DEVELOPMENT OF A SOIL SAMPLING TECHNIQUE AND MEASUREMENT OF DEAGGLOMERATION OF SIX SOILS TO DETERMINE DUST PRODUCING CAPABILITY

CARL A. HAFER

OCTOBER 1960

Contract No. DA-23-072-ORD-1375
Task Order No. 1

OCO, R&D Division
Project No. TB5-1401
DEPARTMENT OF ARMY
Project No. 5B98-09-004

SOUTHWEST RESEARCH INSTITUTE
SAN ANTONIO, TEXAS

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PUBLICATION REVIEW

This report has been reviewed and approved for publication. It is published only for the general dissemination of knowledge and does not necessarily reflect the official viewpoint of the Ordnance Corps.

FOR THE CHIEF OF ORDNANCE

R. G. Streets

ABSTRACT

A technique was developed for obtaining soil samples for purposes of soil particle (dust) size distribution measurement. A method of determining or predicting the dustiness of soils through quantitative measurement of dust size particles within the surface (active) soil is presented. Six soils were exposed to vehicle (M38A1 truck) traffic. Surface soil samples were collected after various numbers of vehicle passes and the size distribution analysis of each sample was made. The deagglomeration or breakdown of the surface soil below approximately 74 microns is assumed representative of the dustiness potential of the soil. Other factors concerning dustiness of soils are discussed.

ACKNOWLEDGMENT

This program was conducted under the administrative direction of Mr. P. W. Espenschade who was Chief of the Environmental Branch, Engineering Sciences Division, Office of Ordnance Research, U. S. Army, at the time the program was active. Mr. Espenschade presently occupies the position of Chief of the Environmental Research Office, ORDLI-EO, Ordnance Technical Intelligence Agency, Office of the Chief of Ordnance, U. S. Army. The cooperation and assistance of Mr. Espenschade was instrumental to the progress of the project.

In addition, the author wishes to acknowledge the equitable assistance of Mr. R. E. Engelhardt, Manager, and to Mrs. Arla Smith, Secretary, Environmental Research Section. The services of the two technicians, R. V. Drury and P. F. Czaja, were instrumental in the collection of the multitude of data. Finally, an acknowledgment of thanks is extended to the landowners who donated the soils used in this program.

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I. INTRODUCTION

Past experience with vehicle operation on off-highway terrain has clearly established the need for additional knowledge of the dust environment commonly associated with such operation. Obscuration and personnel discomfort, like equipment component failures, are directly attributed to the dust plume caused by a vehicle. Although the solution to this environmental problem has been approached in many ways, the actual measurement of the deagglomeration of various soils exposed to vehicle traffic escaped attention. This report concerns the measurement of particle size distribution of soil samples collected from tire paths after a number of consecutive passes. The development of a technique for obtaining a soil sample was of equal importance to this program.

Although the particle size distribution of a soil can be easily measured, this information is not conclusively indicative of the dustiness of the soil. The particles may be in an agglomerated condition which prevents the formation of dust clouds, even though a soil is composed of the necessary amount of fine particles to become dusty. Clay soils, which have a high percentage of minute particles, are particularly noted for compacting into "lumps" or "clods" or may form a hard surface, none of which are considered dusty until some breaking of the particle aggregates occurs.

The most common cause of particle agglomeration is soil moisture. When the soil moisture content is raised to a high percentage and then lowered, the particles become closely knit, with the smaller particles tending to fill the voids between the larger ones. This results in a dense compacted mass. It has also been shown that there is an attraction between the water molecules surrounding adjacent particles of clay.* This action of soil moisture produces a bonding which is responsible for the tensile strength properties of clays; the bonding is another factor responsible for agglomeration.

The military forces are not particularly interested in the dust produced by natural causes such as dust storms because these dust

* Ralph E. Grim, "Organization of Water on Clay Mineral Surfaces and Its Implications for the Properties of Clay-Water Systems," Highway Research Board Special Report No. 40; National Academy of Sciences-National Research Council Publication 629, January 1958.

concentrations are relatively mild. But there is interest in those conditions produced when the terrain surface is mechanically agitated. The previous paragraphs have indicated that the dustiness of a soil is not some constant value, but is more accurately a function of the basic particle size and the state of agglomeration in which these particles exist. To further complicate the picture, severe surface agitation may break the basic particles. Thus the potential dustiness of a virgin soil will essentially be controlled by two variables the percentage of free dust particles and the degree of particle fracture when the soil surface is disturbed.

It is important that some method or technique be developed that will determine the dust potential of a terrain. It is also evident that current laboratory techniques of determining the particle size of soils are not entirely adequate because variation in the sieving procedure, soil sample drying time, and other processes produce significant alterations in the particle size distribution results.

This program was designed to emphasize the influences of laboratory technique on particle size distribution and to show the variation of the resulting values as a function of the degree of soil agitation. Insofar as possible, the influences of moisture content were negated, the theory being that soil moisture is constantly changing in nature and it is important that the dust potential be determined only in the most severe case, that being minimum moisture conditions. The major effort was directed toward establishing the procedure by which a soil sample should be removed from the parent terrain. Verification of the resultant technique was, of course, obtained in the laboratory through analysis of the various samples taken over a range of conditions

Six soils, representing a range of hard quartz to soft limestone, were utilized in this program. Combinations of soil materials were chosen because they are more characteristic of true soils found in nature than pure unconsolidated minerals. In addition to the changes in particle size distribution of various soils exposed to vehicle traffic, occurrences of tire sinkage, soil movement, and other minor soil surface changes necessitated certain data adjustments

Documentation of the experimental phase results is presented in chronological order Specific factors of the program may be correlated in alternate fashion to derive information most appropriate to the reader. For example, should information on one particular soil be needed, that information can be interpreted first with consequent comparison with other soils that were used.

The final expose' of the dust plume created by vehicles moving over unsurfaced terrain remains a task to be accomplished only after adequate knowledge of all conditions becomes available. Through extensive research, investigation, and experimentation, a means of fully understanding the factors associated with the dust hazard can be solved leading to its eventual eradication. Never before have such speed, utility, and demanding performance been required of cross-country vehicles. The consequent problems induced by dust have multiplied considerably and must be immediately recognized.

II. PROGRAM OUTLINE

A. Objectives

The primary objective of this program was to develop a procedure for collecting samples from soils for laboratory dust analyses. The other objective was to measure the deagglomeration characteristics of various soils exposed to repetitive vehicle traffic. The final phase consisted of incorporating the above two objectives, simulating the deagglomeration of soils in the laboratory, and finally, predicting the dust producing capabilities of a soil -- basing such predictions on the particle size distribution of the soil.

The quantitative basis employed in the prediction of the dustiness of a soil eliminates, to a marginal degree, the inherent human psychological error That is, on a quantitative basis, there is not the typical multiple range of dustiness as would be viewed by groups. Depending on the familiarity one has experienced in dust conditions, his reaction will be so governed, and what appears to be an extreme dust condition to him will seem much less severe to a second individual. Synoptic interpretation should be made with the data and results derived in this study.

B. Procedure

The program was set up in a systematic order whereby the experimental limits could be established during operation over the first soil. The factors on which limits were necessary included vehicle speed, sample depth, sample area, sample volume, tire inflation pressure, and other contributory measurements of sieving periods, deagglomeration forces, and weather conditions.

A vehicle speed of fifteen miles-per-hour was established as representative of cross-country military vehicle travel. At a vehicle speed of 15 mph, induced air velocities are of a low magnitude, while the dust material moved from the vehicle path is insignificant. This velocity is easily maintained with the M38A1 military vehicle with no excessive difficulty. Further, the low vehicle speed augmented driver comfort and safety, while minimum stresses and vibrations were induced on vehicle components. Minor adjustments of weight distribution and tire inflation pressure were made to produce runs that were consistently repeated under unchanged conditions of operation.

Vehicle tire inflation pressure was maintained at 25 psi. The front-end alignment was checked and found to be correct. The load on each right-side tire was adjusted by adding ballast such that each exerted equal forces. Tire load was the only deagglomeration variable considered in the program. The initial runs were made with a tire load of 750 pounds per wheel and the second set of runs was made on newly prepared soils at a tire load of 1125 pounds or 150% of the first load. The different loads were used to demonstrate the increase of soil deagglomeration with higher loads.

Naturally, variations of speed, tire pressure, and type of vehicle (wheeled as opposed to tracked) will also affect the rate of soil deagglomeration. Unfortunately, the program funds were insufficient to investigate each of these conditions although these factors can and do exert considerable influence. However, for the purposes of this study, it was only necessary to determine the active or dust producing portion of the terrain surface and it is believed that range of conditions which were used produced a sufficiently accurate delineation of this layer.

The standard nondirectional, cross-country (NDCC) military combat tires were used in all operations over the test soils. This tread design exhibits a noticeable extrusion action of soils when the tires penetrate the soil surface. Although the exact soil displacement was not measured, it was obvious that with each passage of the tire a limited volume of soil was laterally displaced. Nonplastic soils were readily extruded producing greater sinkage while plastic soils exhibited reduced effects. Due to the combination of tire flexure and nonplastic soil movement, there appeared a continuous rotation (agitation) of the soil material such that the upper soil layer was alternately exposed to direct tire action. Tire slip, a definite contributor to soil deagglomeration, was held to a minimum by depression of the clutch pedal concurrent with tire-soil contact.

The remaining features associated with the tires of the test vehicle include methods of controlling the contact zone of the tire within the soil bin in order that wall effects during test operations would be maintained at a minimum.

Impressions taken of the contact zone of the tire tread on a level rigid surface were measured at each wheel under loads of 750 and 1125 pounds, respectively. The average static ground pressures were calculated for the tires by dividing wheel load by contact area. The contact pressures were:

750-Pound Load Per Wheel	
Right Front	40.0 psi
Right Rear	39.6 psi

1125-Pound Load Per Wheel	
Right Front	46.5 psi
Right Rear	50.7 psi

The discrepancy found in the right rear wheel ground pressure is probably caused by the difference in wear between the right rear and right front tires.

The site selected for conducting the vehicle operations over the test soils was within one-half mile of the laboratory adjacent to an infrequently used paved road. The location provided adequate drainage with minimum delay for drying after runs. To insure the same conditions during repeated operation over the soil, the vehicle was operated on a circular course with straight approaches and departures to the soil test bin. The level soil surface was obtained by excavating a "pit" for insertion of the soil-filled bin. A tarpaulin cover was provided for the soil bins during periods of high wind, high humidity, and inactivity between vehicle passes.

The site provided an open level terrain to the east, or windward side, while an incline approximately ten feet in elevation and thirty feet from the base was on the west side parallel to the bins; the site selected proved adequate in almost every respect. Runs over the soil could be made at a rate of approximately 100 vehicle passes per hour. At certain intervals between wind speed of over six to ten miles-per-hour, as few as two or four passes could be made before suspending operations.

The soil bins were fabricated after careful study of the proposed test vehicle, soil types, and test conditions. The bin dimensions were as follows:

Width - 24 inches (approximately four times tire width)
Length - 120 inches (approximately equivalent to one tire revolution)
Depth - 5-1/2 inches

The bins were so designed that handling and transferring operations could be executed with reasonable safety and expediency. A conventional fork-lift vehicle was used for transfer of the prepared soil bins from the laboratory to the field test site.

One important consideration in the design of the soil bins was that of wall effect. Wall effects enter into practically all experiments where movement of a substance is rendered within a container. The wall effects can usually be interpreted as functional properties of the fluid (velocity, viscosity, and density) and/or stationary "carrier" (surface smoothness, turns or bends, and diameter or cross section area discontinuity). These experimental soil deagglomeration studies were no exception and the width of four times the tire tread was the most representative dimension derived for the soils used.

Soil types locally available included both plastic and nonplastic groups thus producing a good representation of the extreme cases. The quartz (sandy) soil was the only material which exhibited difficult control with respect to sinkage and lateral movement and consequent consideration of the wall effects. Only 25 passes could be made over the sand type soil before the soil had to be redistributed. All other soils produced no objectionable sinkage or excessive movement from the standpoint of test control.

In principle, a sinking tire may be assumed to be a source of compressive stresses which, in addition to acting in a vertical plane, also "radiate" toward the sides. Sandy quartz soil can be assumed a pure frictional material lacking cohesive properties. The movement of cohesive or semi-cohesive (frictional and cohesional properties) soils is not pronounced and compaction controls the lateral soil movement within close limits.

Upon initiation of the soil deagglomeration studies, the soils were subjected to vehicle traffic. Several features of the experimental test plans were altered in an attempt to obtain a maximum of useful data. The point of sample collection was changed from position to position and from the center of the tire path to two inches from the tire track center line. An attempt was made to use aluminum foil sheet at subsurface depths for purposes of collecting samples of fine particles filtered through the surface layer. The use of aluminum foil was discontinued after it was learned that the internal grinding action within the soil was too severe, even at depths of 4 or 5 inches.

A grid pattern of smooth, flat, stainless steel pans was oriented adjacent to the soil bin and vertical 12-inch barriers (walls) were erected alongside the flat pans such that all "dust" material failing to pass over the 12-inch walls would be trapped on the level pans. These barriers were used to suppress the "splash" of particles from the bins. The system was found inadequate in that the minute size particles were blown from the pans leaving a skewed distribution containing high percentages of larger particles. The rapid movement of minute particles from these out-of-the-bin collection positions made it necessary that all further samples be obtained from within the soil bin proper.

Experimental test condition limits were established prior to the operation on the soils and the first phase of activity was concerned with checking the validity of these limits Ambient relative humidity and wind velocity were the most important factors governing the periods of vehicle operation Test runs were conducted only during periods of 35 to 55 percent relative humidity and 0 to 10 mph wind speeds.

The vehicle velocity of 15 mph and the direction of travel over the test soils balanced, to a degree, the ambient "head" wind usually prevailing at the test site. A 15 mph vehicle traveling directly into a 15 mph head wind does not exactly balance the dust environment due, mainly, to the large delay experienced by the particles while falling back to the surface The time required for a particle to reach its maximum height above the surface does not equal the time elapsed during the descent of the particle back to the surface. However, the motion of the particles was largely in a plane parallel to the vehicle wheels resulting in a minimum loss of dust particles.

During all field operations the ambient temperature remained above 40°F with peak readings of 106° and 107°F This condition had no important effect on the deagglomeration studies other than drying, thus it was not a limiting factor in the program Drying is, of course, influenced by temperature but this is only a rate effect which was most pronounced in the sandy (quartz) and black gumbo soil (clay-quartz-organic). During actual test operations, the variation in soil moisture content for each individual soil was usually less than four percent. Therefore, external control of the soil moisture content was unnecessary except in extreme cases of rainfall or other periods of high atmospheric moisture. In naturally emplaced soils, soil moisture is supplied in part through capillary action; this moisture increase was eliminated by the moisture-proof floors in the bins

Soil samples obtained from the test bins were carefully transferred to the laboratory, weighed, and placed in drying ovens for a minimum of 24 hours at 160°F. The samples were then sieved and finally analyzed using a Sharples Micromerograph Particle Size Analyzer.

From the sieving operations, two factors were determined; (1) the optimum sample size which allows rapid and accurate separation, and (2) the sieving period for the individual soils. Sieving periods were determined by close observation of changes in density, particle size, and moisture content after specific time intervals. After sieving, sample size and deagglomeration forces were calculated; this identical technique was consistently followed to insure maximum control of the variables.

Before the independent dust condition could be determined for a given soil, there arose the necessity to draw conclusions borne out in previous research with respect to particle size distribution. Some three years ago a program designed around the measurement of dust concentrations around a moving vehicle was performed at the Southwest Research Institute * An isokinetic sampler was developed, fabricated, and calibrated. Samples were obtained at numerous positions around a vehicle traveling at 5, 10, 15, 20, 25, 30, and 35 miles-per-hour. Of all the particle size distributions determined, there were a very minute number of samples in which particles larger than 74 microns were obtained. Based on this extensive measurement program, the particles above 74 microns are therefore considered to be beyond the actual dust range which is likely to be found in a vehicular generated dust plume. Although particles of approximately 100 microns are theoretically lifted by air streams having a velocity of 15 miles-per-hour, actual particles measured did not substantiate the theoretical values. In special cases, the quantity of particles larger than 74 microns may represent several percent (by weight) although the period of flight for such particles is short-lived. Seventy-four microns approximates 3/1000-inch which exceeds the usual clearance between two mating parts or the openings in a filter system. The justification for establishing 74 microns as the upper level in the dust size range is believed adequate based on the above explanation.

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* Reports:

Pauly, James, "A Study of the Effects of Dust on Ordnance Automotive Material," Final Report, Contract No. DA-23-072-ORD-836, Supplemental Agreement No. 4, Task Order No. 9, Southwest Research Institute, Feb. 1956.

Hafer, Carl A., " A Survey and Study of the Factors Which Affect the Dust Environment Created by a Vehicle Operating Over Unsurfaced Terrain," Final Report, Contract No. DA-23-072-ORD-1210, Supplemental Agreement No. 2, Southwest Research Institute, Sept. 1958.

"Petrographic and Particle Size Analysis of Terrain Samples Taken from Vehicle Test Courses at Yuma Test Station, Arizona, and Aberdeen Proving Ground, Maryland," Final Report, Contract No. DA-23-072-ORD-1210, Task Orders 1 and 4, Southwest Research Institute, March 1959.

III. LABORATORY TECHNIQUES

A. Particle Size Distribution as Utilized in Prediction of Soil Dustiness

A method of analyzing surface soil samples must be consistently followed in order to determine the dustiness of a soil. Data must be reduced to a mathematical basis. Further, the data must be obtained through careful analysis of the sample while criteria, which may induce error or invalidate such predictions, should be eliminated. Using a quantitative basis, psychological factors are eliminated, i. e., a surface soil which contains 10 percent by weight of particles below 74 microns will be classified at different dustiness levels depending on individual prior experience in dust environments and observations. Generally, with continued exposure to dust environments an individual becomes very critical in acknowledging the level of dustiness.

For prediction of dustiness of a soil, the following assumptions will be entertained

(1) The dustiness of a soil is first dependent on the fraction or percentage of soil particles in the "dust" range and the distribution of the particles within this "dust" range.

(2) The dustiness of a soil is secondly dependent on the type of vehicle moving over it wheeled, tracked, heavy, or fast, etc.

(3) All soils will be dusty if the moisture content is low enough and the soil is composed of some particles within the dust range (less than 74 microns) and of soil material that will deagglomerate.

In a laboratory analysis only the physical properties of the soil material and the particle size distribution can be accurately determined. Ambient environments to which the soil has been subjected are usually not known in entirety (or detail) and, in any case, are not accurately recorded.

Moisture content in soil is of wide variation and form. The soil can be saturated or it may only be exposed to medium to high relative humidity. The rate of drying of surface soil is dependent on solar radiation and evaporation of soil moisture -- each a function of exposed surface area. Dustiness (a function of moisture) and obscuration are augmented by the dispersant action of prevailing winds or induced air flow of a vehicle.

Current laboratory methods of predicting dustiness are based on the assumption that increased dustiness results with increased percentage of minute dust-sized particles. Minor contributions to dustiness prediction can be made through measurement of relative hardness of the soil particles. Microscopic study indicates the state of agglomeration of the particles.

Breakage of aggregated particles into smaller particles is usually not as pronounced as the deagglomeration of clusters of particles into individual particles. This is readily understood since the compressive strength of soil particles is usually greater than the ground pressures exerted by vehicles.

Usually soils with more than one percent of particles less than ten microns may be considered dusty. As the percentage of particles less than 74 microns increases above approximately 10 percent, the dust potential of the soil becomes pronounced. Because of the wide variations in vehicles and wide range of soil moisture content, no absolute value can be established that would satisfy all conditions. The rate of deagglomeration is not entirely indicative of the dustiness of a soil since a very dusty soil may not have a significant change of the particle size distribution, yet remain dusty during vehicle operation.

B. Particle Deagglomeration

The process of separating clusters of particles into individual grains is very important in the analysis of dust particle size distribution. Particles are "stuck" together with moisture, by chemical association, or ionic attraction. Individual particles are broken down mechanically and, perhaps to a minor degree, thermally. Sharp corners are broken off and cracking takes place along the cleavage planes of the crystalline particulate structure. Laboratory analyses are always preceded by mechanical handling of the soil (particles) sample material. Depending on the shape, hardness, and mineral composition, close control of methods and techniques during analysis must be observed. Moisture content must be maintained at a constant low level; sieving periods must be determined from actual time-rate-of-change experimentation. In addition, ambient conditions of humidity and temperature must be observed and controlled in the laboratory.

Deagglomeration of aggregate particles is effected in the Sharples Micromerograph (an automatic sedimentation weight recording instrument) by discharging the sample through a circular slit formed between two concentric cones. After the two Sharples instrument settings--deagglomerating pressure and slit opening--are determined, complete data for a particular soil can be obtained.

In effect, dustiness is wholly dependent on the deagglomeration of the surface soil material. The greater the deagglomeration, the more percent by weight of particles in the low diameter range, and the higher the dust-producing capability of the soil.

To repeat, the deagglomeration of aggregate particles may result from chemical, mechanical, or ionic action of the soil. The key to predicting the dustiness of a soil lies in determining its deagglomeration characteristics.

Common techniques employed in deagglomeration of aggregate particles and particle size distribution measurements include mortar and pestle, sieving, centrifuge, photo extinction, elutriation (in either liquid or gaseous fluids), and microscopic methods. Direct particle size measurements by sieving and microscopic examination are probably the most accurate; however, correlation of the results of the two processes is difficult and tedious since two entirely different analyses are involved, i. e , distribution by weight and distribution by count. Indirect methods of measurement have been perfected such that the results may be rapidly obtained and are reasonably accurate.

Experience gained in performing particle size distribution analyses of carbon black, zinc dust, boiler fly ash, and sodium tripolyphosphate-anhydrous, to mention a few powder materials, has revealed many peculiarities exhibited by various particulate materials. Pelletized carbon black is effectively deagglomerated in the Sharples Micromerograph*, although bulk carbon black, when compacted only slightly, will not be completely deagglomerated. Boiler fly ash usually contains a minute amount of metallic matter. The metallic particles (rust, etc.) can be observed under the microscope and its magnetic qualities determined. When samples containing magnetic particles are found, the sample must be passed through a demagnetizing coil prior to the Sharples Micromerograph analysis. Zinc dust, having a specific gravity of over 7 g/cc requires very high deagglomeration forces to completely separate the particulate mass.

Effects of moisture can best be observed microscopically. Sieving, discussed elsewhere in this report, profoundly illustrates the effects of high relative humidity on sieving operations. Minute particles, especially those possessing hygroscopic properties, become agglomerated into small balls which roll across the sieve screen during periods of sieving in ambient environments of high humidity.

* See description in second paragraph of this section.

Effects of humidity are extremely difficult to analyze in any elutriation or sedimentation process in which the gaseous settling medium is different from the ambient air. Elutriation and sedimentation processes employ a gaseous fluid with fluid conditioners such as silica gel. The Sharples Micromerograph utilizes dry nitrogen as the sedimentation fluid. When a dry gaseous fluid is utilized, the initial deagglomeration is most important because the humidity is dispersed in the dried gas after contact of the particles and the gas. Therefore, it is impractical to correlate the percent of relative humidity and the state of agglomeration of particles when the actual relative humidity does not remain constant after mixture in another gas.

Particle deagglomeration caused by vehicle traffic can be interpreted only within the accuracy of modern equipment and techniques.

C. Microscopic Examination Of Dust Particles.

Only brief microscopic examination of various soil samples were made in this study. The two primary elements of examination were shape and agglomeration of particles. The following table illustrates the results of the examination.

TABLE OF MICROSCOPIC EXAMINATION

Sample	Shape	Primary Agglomeration	Remarks
SL-4	angular	well-separated particles	silica-quartz
SL-5	irregular to subround	few aggregate particles	many below 5 microns
SL-6	angular to subround	many agglomerated particles	high organic material content
SL-7	tabular and irregular with few rounds	small particles separated; larger particles agglomerated	low feldspar content
SL-8	subround to irregular	highly agglomerated	minute particles attracted each other
SL-9	subround	fairly well deagglomerated	good distribution

Slides were made using glycerine as the dispersing suspension fluid. Sets of slides were made of various soils from samples taken after consecutive vehicle passes. Many of the particles showed no appreciable change in shape due to additional passes. The only significant change noticed was in the increase in rounded corners or absence of sharp corners.

Several of the silica soils exhibited more or less complete separation (deagglomeration) after a number of passes. There were also cases where the distribution reversed the trend of deagglomerating after repeated passes; however, the causes for this action may be one or more of the following:

(1) Operator technique or methods used in obtaining samples may be different for several personnel.

(2) The smaller particles are removed from the bin area at a more rapid rate than they were mechanically produced.

(3) Small particles sifted down into further depths in the soil and were therefore not contained in the sample collected from the surface.

(4) By chemical, mechanical, or ionic attraction small particles became attracted or attached to each other, resulting in larger particles during the analysis.

D. Sieving of Soil Material

The following paragraphs concerning sieving are restricted to the standard 8-inch diameter, U. S. Bureau of Standards Series, brass wire mesh sieves.

The sieving period for each individual soil was determined by measuring the change in weight of material passing through the set of sieves and choosing a time period such that the change remained constant and at a low value. Resulting sieve periods varied between six and eight minutes to twenty minutes for a 20-gram sample. Curves of the sieving rates for the six soils are shown in Appendix D. The limestone soil (SL-5) indicated a gain of four percent during the first 20 minutes sieving period and less than two percent gain during the next period of 40 minutes. From the family of curves in Appendix D it can be seen that all except the quartz (SL-4) and creek-bed soil (SL-8) showed a decreasing change of percentage particles passing the No. 200 (74 micron) sieve with increasing sieving period.

Because breakage is more pronounced in a friable soil, the sieving period for clay or soft soils is more critical than for hard (quartz) abrasive soils.

Temperature and humidity must be maintained within close tolerances in order that agglomeration of particles due to moisture does not significantly affect the results of sieve analysis data. Sieving was performed in ambient conditions of 40 to 50 percent relative humidity and between 70° and 80°F. Samples were dried prior to sieving at approximately 160°F in excess of four hours.

The mechanical motion of the sieve shaker was that of an arc approximating three degrees displacement. The radius of the arc of the lower (#200 - 74 micron) sieve screen was approximately 21-1/8 inches. The lateral movement of the #200 screen was 608 inches per minute at 595 movements per minutes.

A particle below 74 microns has to descend approximately 6-1/2 inches which is the distance from the top sieve to the bottom pan. By the same token, a particle of 2 microns diameter requires approximately 2-1/2 minutes to fall through this distance. It is interesting to note that the horizontal movement at the #200 screen has an average displacement of 10.1 inches per second while the vertical "fall" of a 2-micron particle is on the order of 0.213 inches per second -- a ratio of 47 to 1. The above statements are misleading in that mention is not made of deceleration, changing directions, and acceleration of screens which, combined, invalidates most of the process of dust particles floating downward.

Curves depicting the "sieving rates" of each of the six soils are included in Appendix D. "Sieving rate" may be defined as the percent of total soil sample passing through the #200 (74 micron) screen in a specific period, i.e., during the initial minutes some 2 percent per minute pass through the screen and after a short period of approximately 10 minutes the gain decreases to 2 percent per 10 minutes or less. When the gain becomes constant for a specific soil, the remaining samples are sieved for a like period.

Each of the six soils was sieved for a period of one hour during which time weights of the sample on each screen were recorded after 5, 10, 20, and 60 minutes, respectively.

A limestone (SL-5) soil showed a higher rate of gain than any of the other five soils. There is some correlation between hardness and rate of gain of sample passing through the No. 200 sieve. The quartz (SL-4) and creek bed sand-gravel-clay (SL-8) soils had the lower sieving rates.

The clay-sand soil (SL-9) was found to exhibit a distinct particle size distribution for each mineral fraction. The clay fraction included most particles below approximately 50 microns whereas the larger particles were primarily quartz. A double "S" curve illustrates the quartz and clay fraction very clearly. A particle size analysis having normal probability distribution results in a smooth "S" curve on a semi-log (particle diameter vs percent weight less than diameter) plot. Very few of the samples exhibited normal probability particle size distributions.

E. Important Factors In Soil Sampling

1. Sampling Procedure

The following paragraphs present a technique for obtaining a soil sample for utilization in dust producing determination. The objective of obtaining a soil sample is to analyze the sample with consequent laboratory prediction of deagglomeration (or dustiness) due to future vehicular traffic.

With respect to dust soils, a sample should be taken from a location presenting characteristics of maintaining negotiable vehicle traffic. Land areas containing continuous moisture levels exceeding approximately 20 percent will usually have no bearing on dust generation. Alternate elevations with corresponding strata formation must be represented with individual samples. Proper interpretation of the intended traffic or operation must be made before a particular soil sample is discounted for reasons of unanticipated future uses. All classes or modes of vehicle operation should be construed for reasons of obtaining the sample. Helicopters are applicable transportation for the collection of soil samples.

For subsequent laboratory analyses adaptation, a soil sample should be taken that will provide data applicable to forecasting of the dust generating capability of a soil. Deagglomeration of both large and small aggregate particles occurs at a rate dependent on soil type, moisture content, and grinding medium.

The sample should include those particles found on or near the soil surface. For purposes of dustiness prediction or determination what may be called the "active layer" is of interest. The "active layer" is essentially that which may, in the future, be disturbed and/or changed by the action of the vehicle track media. In the case of most military vehicles, sinkage in the dry loose soils (SL-4) is basically a function of the number of vehicle passes. The quartz (SL-4, SL-4A) soil confirmed this theory in that lateral movement of the soil was so severe that it had to be redistributed in the bin. Therefore, in nonplastic soils only, samples from several depths would offer representative data for dustiness forecast.

Samples from plastic soils obtained from depths of 0 to 1/2 inch are representative of the active or dust generating layer. Practically all plastic soils will compact; however, one-half inch usually exceeds rubber tread depths. Recommendation of one-half inch sample depths is based on close observations of sinkage in the soil test bins. Since compaction cannot be divorced from track sinkage, the depth at which the soil is agitated and made available to the dust plume, through both mechanical and aerodynamic propulsion, can be considered in dustiness analysis.

Soils (excluding sands) displaying high sinkage characteristics require analysis of the aggregate mass exceeding one-half inch depth. Samples obtained from depths exceeding one-half inch should include soils from individual strata. Subsoils should be included in additional separate samples. Although moisture is of great importance, no precaution should be made in obtaining a sample of low moisture content, except where considerable slaking would render the sample unsatisfactory for representative soil dust analyses.

Several important aspects of sampling procedure must be kept in mind. For example, samples should not be collected from washed sand, from stream beds (except in case where it is considered for land vehicle travel), from sand dunes (which produce no dust), and from terrain remote to military land travel application.

Vegetation is of importance, and to date no precise measurement has been made in determining its contribution to dust plume. Consequently, plants and vegetation promote dustiness or reduce dustiness, depending on plant age and ambient weather conditions. During periods of dawn (and dusk) plants tend to hold moisture, causing dust particles to adhere to leaves and branches. The fibrous characteristics of plants allow particles to adhere to the surfaces. Upon drying, considerable agitation is promoted by surface winds or rebounding of plants. In some cases, the vegetation actually makes contact with the soil, resulting in a sweeping action with subsequent high dust particle movement.

As with any type of sampling, the practice of proper packing, labeling, shipping, and storage cannot be overstressed.

2. Sample Size

A sample, representative of the proposed traffic route, composed of 75 to 100 grams (approximating the volume of a cigarette pack) should be placed in a metal or leak-proof container. The filled container should be closed and correctly labeled or coded and the code, with related information, entered in a log book. Except for protecting the sample from moisture and leakage from the container, the sample is ready for shipment to the laboratory for analysis. Any of several methods may be employed for packing and shipping the soil sample. For multiple samples, they may be placed in a sectioned wooden or cardboard box. When glass containers are used, adequate packing filler material should surround the individual containers to prevent breakage. One-half pint, wide mouth jars are excellent for such purposes.

Only very small fractions of a gram (1/20 gram approximately) are measured for particle size distribution below 74 microns. However, in order to obtain reasonably accurate data on the particle size percentages in the sieve size ranges, a considerably larger sample is required. In addition, 15 to 20 grams are required for density measurement.

IV. RESULTS

The results obtained from each soil, with the two wheel loads, are presented concurrently.

A. Quartz Soil - Codes SL-4 and SL-4A

The quartz soil consisted of a mixture of silica grains with a small (less than 3%) fraction of iron and clay-stained particles. Moisture content of the soil was 0 to 2.0 percent. The percentage of particles below 74 microns remained between 6.6 and 5.2 throughout the 250 vehicle passes with the 750-pound per tire load. During the 150 passes with a 1125-pound per tire load, the percentage of below 74 micron particles varied from 9.0 to 6.6.

During vehicle operation on the quartz soil there was continuous lateral movement of the material from the tire path. Sinkage of tires was excessive in the quartz soil and soil material had to be replaced after each 25 runs.

The specific gravity of the quartz soil was calculated as 2.58 grams per cubic centimeter. An optimum sieving period for a 20-gram sample was determined as 12 ± 2 minutes. The sieving period is determined from a sieving rate curve when the rate of increase of particles passing through the lower screen (#200; 74 micron openings) becomes constant at a very low rate. The graphical illustrations of the sieving rates are presented in Appendix D. Specific information concerning sieving is presented in a later chapter.

The percentage of sample in specific size ranges can be observed in Appendix B. The mathematical relationship between specific dustiness (percent by weight of particles below 74 microns) and number of vehicle passes was derived for the quartz soil subjected to the 1125 pounds per tire load. The expression assumes the form:

$$p = \frac{\log R + 3.168}{53}$$

where: p = percentage (decimal) of total soil sample below 74 microns

and R = number of vehicle passes

The change of particle size distribution found with operations of 750 pound per wheel loads showed no specific correlation.

The basic equation $p = \frac{\log R - \log C}{m \log 10}$ has constants m and C which may be solved by equating two logarithmic equations with two unknowns. By choosing two points on the semilogarithmic curve and knowing both p and R for each point, the equations can be solved for constants C and m. The preceding equation is applicable only for quartz soil exposed to M38A1 vehicles loaded to approximately 1100 pounds per wheel.

Since there was no significant change or indication of increasing dustiness with additional vehicle passes in the initial vehicle operations (750 pound load per wheel), one or more of the following assumptions may be entertained:

(1) The rate of deagglomeration approximated the rate of loss of particles due to ambient and induced wind action.

(2) The combined loss of particles caused by descent to subsurface soil depths and ascent to the atmosphere offsets the manufacture (by deagglomeration and fracture) of particles by tire action.

(3) The particles were not deagglomerated to the extent that a change in percentage could be determined.

Numerical data in Appendix B and graphical presentation of this data in Appendix C indicate the specific condition of the soil after a given number of vehicle passes. The small particles represent a minor portion of the surface soil with subsequent few particles remaining airborne behind the moving vehicle. An excellent example of negligible dustiness can be found in operation on beaches or windswept deserts where the actual dust plume caused by a vehicle does not exceed eight or ten inches.

The belief that no dust particles are manufactured with relatively mild (250 vehicle passes) traffic was not confirmed by the data obtained on this soil. Contentions of some soil scientists are that sandy soils are not actually fractured by vehicles but merely deagglomerated and, further, thousands of vehicle passes are necessary to effect a slight change (say one percent in any size range, i.e., 0-5μ*, 5-10μ, 10-20μ, etc.) in particle size distribution. From this basic study it may be shown that there is fracture as well as deagglomeration of the quartz soil at less than 150 vehicle passes.

* μ denotes microns

When operated upon with light loads, the quartz soil does not fracture and/or deagglomerate such that it contains the necessary 10 percent of particles below 74 microns to be classified as extremely dusty. The change of the particle size distribution of soils subjected to high (1100+ lb load per wheel) can be measured with 150 runs.

B. Limestone Soil (SL-5 and SL-5A)

The soft limestone soil consisted of soft tabular-shaped particles in generally high states of compaction. The limestone soil was screened to remove clods in excess of 1 by 1/2 inches. With very minor agitation extreme dusting of the soil was encountered. In view of the severe deagglomeration of the limestone soil, extreme caution was exercised during vehicle operation thereon. Wind speeds exceeding approximately five miles per hour halted vehicle operations as did relative humidities exceeding 50 percent.

Except for the black clay gumbo soil (SL-6), the limestone exhibited the highest percentage of particles below 74 microns. A maximum of 20.8 percent (of below 74 micron particles) occurred in the soil sample obtained after 50 vehicle passes. Only 13.6 percent was recorded for the sample obtained after the first pass. Samples taken from depths of 2, 3, 4, and 5-1/2 inches (on floor) contained 20.8, 17.9, 15.1, and 22.2 percent, respectively, of particles below 74 microns. The high 22.2 percent occurring in the sample obtained from the bin floor indicates a descent of minute particles through the soil - much the same as slaking.

Compaction occurred due to the vehicle passes with approximately 2 inches sinkage after 250 runs. Compaction of the soil exposed to a higher load resulted in fewer dust (below 74 microns) particles.

Moisture content of the limestone remained below 4 percent throughout all the runs. Relative humidities of approximately 60 percent caused pronounced agglomeration with clogging of sieve openings.

A curve illustrating the change in percentage of particles below 74 microns with consecutive numbers of passes is included in Appendix B. Specific data concerning the percentages in various size ranges for each sample are presented in numerical form in Appendix B. Cause for the transition phase between 50 and 100 passes (refer to data in Appendix B) is not completely understood since the samples were taken 20 minutes apart with only 2 percent humidity change (62 to 60% RH) and an ambient temperature rise of 2°F (86° to 88°F) with constant wind velocity between 1 and 2 mph. From the curve (Appendix C), it appeared that the soil surface was dry and, upon removing the cover, agglomeration due to humidity became eminent and shortly thereafter solar radiation caused the surface soil to become dry. The particles, lacking cohesive media derived from humidity, were carried aerodynamically from the bin or the minute particles descended into the voids at a faster rate than fine particles were manufactured.

In the second paragraph it was indicated that the highest (22.2) percentage of below 74 micron particles was located on the bin floor or approximately 5 inches below the soil surface. The question arises as to the period of runs (0 to 25, to 50, to 200, etc.), in which minute particles descended through the soil; however, due to the unquestionable packing of the soil, it is believed that the greatest descent occurred during the initial runs and the descent rate decreased with increasing numbers of runs.

The operations conducted on the limestone soil were during ambient temperatures of approximately 80°F, relative humidities of 40 to 50 percent and ambient wind velocities of 1 to 4 miles per hour. Sieving periods for the limestone were six to eight minutes.

The specific dustiness (percentage by weight of particles below 74 microns) for a specific number of vehicle passes can be shown as having the following relationship.

750 lb per wheel load — 250 vehicle passes

$$p = \frac{\log R + 20.579}{122.2}$$

where: p = percent (decimal) of total soil sample below 74 microns

and R = number of vehicle passes

1125 lb per wheel load — 150 vehicle passes

$$p = \frac{\log R + 5.652}{72.2}$$

constants p and R are the same as before

The limestone soil was considered extremely dusty after as few as five passes. Sinkage was only 1 to 2 inches after 250 passes.

C. Black Clay Gumbo Soil (SL-6 and SL-6A)

The fertile black soil is composed of clay, silica, and organic matter. The soil supports vegetation and has high moisture retention.

Initially, the material was highly agglomerated into one-half inch "clods" which were difficult to separate except by vehicle tires or tracks or by increasing the moisture content above the plasticity limit. Specific gravity of the black gumbo soil was calculated as 2.51 g/cc.

A continuous increase in the percentage of particles below 74 microns was indicated throughout the 250 runs. The percentage of particles below 74 microns increased from 1.1 to 12 during the runs. Plot points of the percentage of sample below 74 microns vs number of vehicle passes exhibited a uniform gain, thus contributing to constant deagglomeration of the soil and soil clods.

Sinkage was minor in the black gumbo soil except at moisture contents higher than approximately 25 percent. Moisture content, not a primary factor in this study, varied between 5 to 20 percent while the plastic limit of the soil was 37.1 percent. Compaction of the black gumbo soil is very pronounced in the 10 to 20 percent moisture range. Due to the black surface, solar radiation reduced the moisture content of the surface soil rapidly and after 20 or 25 passes the surface material became powdery and dusty.

During the 1125 pound per wheel runs a moisture content level approximated 5 to 10 percent higher than when the 750 pound per wheel load was maintained. Therefore, sinkage was more pronounced and dustiness became less severe with additional vehicle traffic.

Although complete data on the change in particle size distribution can be consulted in Appendix B (SL-6 and SL-6A codes) and a graphical expression of this change in particle size distribution is to be found in Appendix C, the mathematical formula of the curve takes the form:

750 lb per wheel load 250 vehicle passes

$$p = \frac{\log R - .857}{12.9}$$

where: p = percentage (decimal) of total soil samples below 74 microns

and R = number of vehicle passes

1125 lb per wheel load 150 vehicle passes

$$p = \frac{\log R + 3.468}{52.3}$$

constants p and R are same as before.

Relative humidities exceeding approximately 60 percent curtail separation of particles, and continued exposure to high humidity conditions reduces the dustplume markedly. After removal of vegetation and with surface soil moisture content less than approximately 25 percent, the black gumbo soil may be considered extremely dusty.

D. Decomposed Granite Soil (Codes SL-7 and SL-7A)

The soil material referred to in this category consisted of decomposed granite with inclusions of mica and silica grains. As a result of severe weathering, many of the particles were irregularly shaped. A density of 2.50 g/cc was calculated for the granite soil. Slight sinkage was exhibited by the granite soil with moderate compaction during the 250 passes.

A threefold increase of below 74 micron particles was measured during the 250 vehicle passes with 750 pound load per wheel. During these runs the increase of dust particles was 3.5 to 10.3 or 6.8 percent. The percentage of particles within the dust range (to 74 microns) was 15.2 after 150 runs with a 1125 pound load. The median diameter of the dust fraction remained less than 15 microns during the measurements.

Deagglomeration of the granite soil was consistent throughout the dust size range during the continued exposure to vehicle traffic. A peculiar characteristic exhibited by the soil was the hard crust or shell formed on the surface when the soil was wetted and dried. The appearance of the crust was that of "desert pavement." The hard layer is thin and deceiving since it will not support vehicles without fracture of the crust; however, very heavy loads can be carried over the soils safely.

Effects of relative humidity were not pronounced in the granite soil and the moisture content remained between 0 and 4 percent.

The specific percentage of dust-size (below 74 microns) particles in the samples collected after consecutive vehicle passes can be expressed in the form:

750 lb per wheel load 250 vehicle passes

$$p = \frac{\log R - .798}{31.5}$$

where: p = percentage (decimal) of total soil samples below 74 microns

and R = number of vehicle passes

1125 lb per wheel load 150 vehicle passes

$$p = \frac{\log R - 1.544}{1.6}$$

constants p and R are same as before.

Sieving time for the granite soil was 18 minutes. Progressive dustiness conditions were experienced with operation over the granite soil. Approximately 200 passes were required with the 750 pound load per wheel before the percentage of total surface soil sample contained 10 percent with the (0-74 micron) dust size range.

E. Leon Creek Sand-Gravel-Clay Soil (Codes SL-8 and SL-8A)

The Leon Creek soil was a composite material ranging in size from 1 to 2 microns to 1/2-inch pebbles. Included in the mixture were clay, silica, marine shell, and other minerals. The source of the material, being at one time a river bed, exhibited a wide variety of particle shapes, i. e., large subround particles to small irregular shaped particles. The soil was initially agglomerated to a minor degree and after approximately 150 vehicle passes (750 lb per wheel load) the percentage of dust particles remained almost constant at 7 percent.

One to 2 inches sinkage occurred during the 250 passes. A sieving period of 8 to 10 minutes was determined best since a near constant rate of gain through the No. 200 (74 micron) sieve occurred after approximately 5 minutes.

Moisture content of the creek bed soil remained below 2 percent. Specific gravity of the soil was calculated as 2.52 g/cc.

A maximum percentage of 7.1 of particles below 74 microns was measured after the 250th pass (750 lb per wheel load). A minimum of 1.6 percent occurred after the initial pass. The particle size analysis data is included in Appendix B. Graphical presentation of data is presented in Appendix C.

A mathematical relationship of the specific percentage of particles vs the corresponding number of vehicle passes takes the form:

750 lb per wheel load 250 vehicle passes

$$p = \frac{\log R - 1.512}{1.6}$$

where: p = percentage (decimal) of total soil samples below 74 microns

and R = number of vehicle passes

1125 lb per wheel load 150 vehicle passes

$$p = \frac{\log R - 1.544}{1.6}$$

constants p and R are same as before.

The Leon Creek bed soil was considered to be only moderately dusty below 150 passes and becoming very dusty after approximately 200 passes.

F. Clay Soil (SL-9 and SL-9A)

The clay soil was composed of clay and fine grain sand. It was highly agglomerated into 1/2-inch to 1-inch clods which separated readily when exposed to traffic. The probability distribution study of this soil indicated that particles below 40 microns are of clay origin while larger than 40 micron particles are of the silica quartz groups. Probability distribution curves (2) illustrating this change are included in Appendix D. A soil composed of two basic distinct soil types usually exhibits peculiar characteristics of packing, deagglomeration, and changes in particle size distribution. The uniformity of the soil mixture resulted in continuous deagglomeration. The sinkage at the end of 250 passes was measured at 2 inches. The particles below 74 microns increased from 7.2 percent after the first run to 21.2 percent after the 250th run. After 100 vehicle passes the percentage of dust-size (0 to 74 microns) particles remained almost constant at 20 percent.

Density of the clay-sand soil was 2.46 g/cc. The sieving period was determined at 6 to 8 minutes. Curves illustrating the sieving period vs percent of total sample passing the No. 200 (74 micron) sieve are presented in Appendix D. Moisture content varied between 1 and 8 percent, based on dry weight.

The specific percentage of particles within the dust (0 to 74 micron) range vs the corresponding number of vehicle passes can be expressed by the mathematical relationship:

750 lb per wheel load 250 vehicle passes

$$p = \frac{\log R - 1.1584}{0.226}$$

where: p = percentage (decimal) of total soil samples below 74 microns

and R = number of vehicle passes

1125 lb per wheel load 150 vehicle passes

$$p = \frac{\log R - 1.073}{0.802}$$

constants p and R are same as before.

The clay-sand soil, with a maximum 21.2 percent of the total soil sample below 74 microns, can be classified as a severe dust producing soil.

V. CONCLUSIONS

Dustiness is greatly influenced by the packing or state of agglomeration of the surface soil. The severity of dust conditions is purely subjective and remains to be interpreted quantitatively with emphasis on subsequent utilization of dustiness prediction. Highly compacted soils, although composed of high percentages of particles in the dust-size range (below 74 microns), do not result in the levels of dustiness of soils packed to lesser degrees having lower percentages of dust-size particles.

Any soil material composed of more than one percent of particles (by weight) less than ten microns size, especially the clays, limestones, and severely weathered hygroscopic materials, will exhibit conditions of dustiness when subjected to vehicle traffic. Depending on the mineral, deagglomeration or breakdown may progress to a state such that all particles are free of sharp edges or loosely attached fine particles with practically no ensuing airborne dust plume effected by a moving vehicle. These conditions of no dustiness are found on sandy beaches or in locales where no appreciable percentage of minute dust particles remains after continued exposure to ambient winds, subsurface moisture, and agitation due to wind and water. Where deposits of hard quartz sand prevail, large particles allow the minute particles, which may be mechanically manufactured, to descend into the voids, thus never becoming available to the dust plume of a vehicle.

The hygroscopic qualities of a soil material determine its chemical disassociation characteristics. The rate of solubility is a function of porosity and chemical composition, as well as the surface area of the soil particles. Prior exposure to mechanical agitation such as is caused by tires and tracks is instrumental in the degree of compaction, thus the deagglomeration capability of the soil. The grinding action of a soil, with low moisture content, results in a distribution of particle sizes (diameters) approaching a statistical probability such that near perfect packing may be possible. However, such conditions do not exist because there is continuous movement of the surface soil. Penetration of track grousers or tire treads and air movement are primarily responsible for exposing and lifting particles from below the surface.

The soil sampling technique derived in this study indicates that samples should originate from the top one-half inch of soil. The sample should contain a minimum of material such as vegetation, wash sand, and other materials remote to dust generation. A small (approximately 75 to

100 gram) sample should be collected. Major emphasis should be placed on obtaining a natural, undisturbed, and representative soil sample which can be accurately analyzed in the laboratory for prediction of soil dustiness.

In addition to the fact that a given percentage of the dust particles is within the 0-74 micron range, the degree of dustiness depends further on the distribution (by weight) of the particles within the dust range. A composition having fifty percent of the dust particles in the 0 to 10 micron range will be considerably more dusty than one composed of 50 percent in the 0 to 40 micron range. The numerical value determining a dusty condition appears to be a soil having more than 10% of its particles below 74 microns.

The above percentage is based on light vehicle operation. In addition, it is assumed that the soil moisture content is such that particles are freely removed from the soil surface. Modifications should be made in dustiness predictions where heavy vehicles and tracked vehicles are to be utilized. The extent of the modification is not known and additional data are required before modification factors can be established.

The range at which a soil may be considered dust is the result of careful study of both Yuma and Aberdeen test course soil particle size distributions and on two Southwest Research Institute test tracks. The two SwRI test tracks were surfaced with (1) Track A - quartz-clay-gumbo soil (very similar to SL-6) and (2) Track B - limestone-quartz-clay soil exhibiting composition between SL-5 (soft limestone) and SL-8 (creekbed quartz-clay) soils.

The airborne samples collected on the two SwRI tracks varied widely in concentration at different collection positions and speeds. However, the particle size distribution of the total soil sample always exceeded 10 percent of particles below 74 microns when the dust plume became severe to six feet; i.e., visibility was less than 50 feet and the vehicle exterior surfaces became covered with films of dust particles.

During operations over the six soils, the dustiness conditions were considered equally severe with the lighter, M38A1 vehicle. Repeating an important factor -- the numerical percentage herein established does not denote the abrasive severity or the dust concentration resulting during operations. The two preceding factors depend on may additional factors including moisture, ambient wind and temperature, and vegetation.

In view of the wide range possible in particle size distribution of a soil, definite numerical values must be established to identify the range at which dust plumes and severe dust environments may be generated, exclusive of moisture content. Finally, a soil will be dusty if three factors are present: (1) the soil mass consists of an adequate supply of minute (dust) size particles, (2) the soil has a low moisture content such that particles are easily separated, and (3) there is present a means of agitating the soil such that a dust plume is generated.

VI. RECOMMENDATIONS

It is recommended that additional data be obtained from soil sites where various vehicles are used in order to supplement the data of this report. Correction factors for vehicle type, operation, and condition of soil should be derived to aid in accurate dustiness predictions. Interchange of information and data between organizations should evolve mobility concepts whereby precise future land operations can be described in detail sufficient to control or allow for the dust environment in any locale.

APPENDIX A

Appendix A contains a description of the equipment utilized in this program. A brief description of the test conditions is presented to refamiliarize the reader with important features of the program.

A. Analyses Equipment

1. Sieves

A set of Tyler standard U. S. Sieves was employed for initial separation of the soil samples into the following size fractions: over 250 microns, above 140 microns, above 105 microns, and above 74 microns. The particles below 74 microns were collected in a pan. The screen designations of the above size ranges are No. 60, No. 100, No. 140, and No. 200, respectively A standard sieve shaking machine having approximately 300 cycles of oscillation per minute was used.

2. Drying Ovens

Thermostatically controlled, electrically heated, laboratory ovens were employed in the drying of all soil samples. The volume of the ovens was approximately one cubic foot each. The temperature range of the ovens was ambient to 200°C (328°F) with an accuracy of ± 1°C (1.8°F).

3. Humidity Controlled Storage Chamber

An insulated storage cabinet was used for storage of all samples after drying and between particle sieve analysis. The relative humidity inside the cabinet was maintained at low levels (approximately 30%) through the use of silica gel placed at different levels inside the chamber. The gel was reactivated daily.

4. Density Measurement Apparatus

Soil density was measured with a standard laboratory pycnometer of 50 milliliter volume. Chemically pure toluene was employed as the liquid wetting agent. Density measurements were made using dried soil samples. Density and specific gravity are analogous when the metric system is employed.

5. Particle Size Distribution Analyzer (Sharples Micromerograph)

The Sharples Micromerograph is an instrument which provides a rapid determination of particle size distribution by weight of powdered materials through the application of Stokes' Law of Fall for the velocity of particles falling through a gas.

The basic operating principle of the Micromerograph is simple. A well deagglomerated cloud of particles is introduced into the top of a closed sedimentation column, and the particles are allowed to fall through an inert gas (nitrogen) onto the pan of a servo-electronic balance at the bottom. The accumulated weight on the pan is instantaneously counter-balanced by an electrical (restoring torque) current (field) and recorded on a moving chart "milliameter" recorder. This chart, a record of weight increase versus time, is converted into a continuous particle size distribution curve through the use of a template incorporating Stokes' Law. The "size" measured by the Micromerograph is the equivalent diameter of a sphere which would fall at the same rate as the actual particles of the sample. The percentages are calculated and a curve of diameter in microns vs percentage less than diameter is drawn on semilogarithmic paper. An ideal "probability" distribution results in a smooth "S" curve. An example of particle size distribution of clay-quartz (SL-9) is presented in Appendix D.

B. Test Conditions

1. Test Vehicle

Type: M38A1 1/4-ton Truck, 4 x 4 (operated 4 x 2)
Tires: 6-ply Combat, NDCC, 25 psi Inflation Pressure
Speed: 15 mph
Load per Wheel: 750 pounds, 1125 pounds
Number Vehicle Passes: 250, 150

2. Climate

Temperature Range: 61° to 105° F
Humidity Range: 30% to 65% (Relative)
Wind Speed: 0 to 15 mph
Wind Direction: 0° to 225° (north, east, south, southwest)

3. Test Course

Adjacent to paved bituminous asphalt highway. Test soil bin approach covered with tarpaulin.
Track Direction: South 10° east to north 10° west
Test Vehicle Direction: Southward

4. Test Soils

Code SL-4: Hard Quartz Sandy Soil, Density 2.58 g/cc
Code SL-5: Soft Sedimentary Limestone, Density 2.53 g/cc
Code SL-6: Organic Black-Gumbo Soil, Density 2.51 g/cc

Code SL-7: Decomposed Granite Soil, Density 2.50 g/cc
Code SL-8: Sandy Creek-bed Sediment and Gravel Soil, Density 2.52 g/cc
Code SL-9: Clay-Sand Soil, Density 2.46 g/cc

5. **Test Soil Bin**

Dimensions: 120 x 24 x 6 inches deep
Location: Adjacent paved roadway
Material: Wood covered with felt paper

APPENDIX B

Appendix B contains numerical analysis data concerning the soil sample particle size distribution versus number of vehicle passes. In addition, the distribution of the particles obtained from different depths after the 250th and 150th vehicle passes is presented for the 750-pound wheel load and 1125-pound wheel load, respectively.

Particle size distributions of the total soil samples and for the dust fractions (0 to 74 microns approximately) of each sample are presented.

The extent to which the numerical data were applied to this study encompasses one figure, i. e., dust conditions become eminent when ten percent of the total sample are below 74 microns. For a second figure, when one percent of the total sample is below ten microns, a soil can be considered as very dusty.

Graphic presentations of data contained in Appendix B are made in Appendix C.

PARTICLE SIZE DISTRIBUTION OF QUARTZ SOIL (SL-4) 750-Pound Wheel Load

Particle Size Distribution - Percent by Weight of Dust Fraction, 0 to 74u approx.							
	NUMBER OF VEHICLE PASSES						
	0	1	5	10	25	50	100
0 - 5u	2.0	No Sample Collected	3.0	3.5	3.5	2.5	3.5
5 - 10u	3.5		6.5	9.2	8.2	4.7	8.0
10 - 20u	4.0		15.5	15.6	15.3	8.6	10.5
20 - 40u	10.0		22.0	24.7	25.3	16.2	16.0
40 - 74u	59.5		42.5	44.0	37.7	28.0	38.0
Over 74u	21.0		10.5	3.0	10.0	40.0	24.0
Median Size	59.0		43.0	37.0	37.5	63.0	53.0
Particle Size Distribution - Percent by Weight of Total Sample							
0 - 5u	0.12*	No Sample	0.21	0.223	0.215	0.21	0.247
5 - 10u	0.21		0.46	0.587	0.505	0.40	0.562
10 - 20u	0.24		1.09	1.010	0.940	0.74	0.742
20 - 40u	0.60		1.55	1.590	1.570	1.39	1.124
40 - 74u	3.56		2.98	2.890	2.310	2.41	2.658
(0 - 74u, Total)	4.73		6.29	6.300	5.540	5.15	5.333
74 - 105u	4.01	No Sample	4.25	4.450	5.220	4.51	4.039
105 - 150u	5.49		5.26	8.520	6.140	6.44	5.468
150 - 250u	22.20		22.80	23.400	24.600	25.80	23.437
Over 250u	63.57		61.40	57.40	58.500	58.10	61.718

*The fractions are carried through the third decimal in order that minute percentages, especially those of the hard, abrasive soils, can be established for the narrow size ranges. Minute changes in particle size distribution can be readily detected when a high degree of accuracy is employed.

(Cont'd.)

PARTICLE SIZE DISTRIBUTION OF QUARTZ SOIL (SL-4)

750-pound Wheel Load

Particle Size Distribution - Percent by Weight of Dust Fraction, 0 to 74u approx.				
	NUMBER OF VEHICLE PASSES			
	150	200	250	6" Below Surface
0 - 5u	4.2	3.5	7.3	4.7
5 - 10u	8.0	7.0	11.7	7.5
10 - 20u	11.0	9.5	14.0	13.3
20 - 40u	20.5	18.5	23.5	28.0
40 - 74u	39.5	31.5	36.0	43.5
Over 74u	16.8	30.0	7.5	3.0
Median	45.7	53.0	33.5	37.3
Particle Size Distribution - Percent by Weight of Total Sample				
0 - 5u	0.335	0.324	0.456	0.225
5 - 10u	0.638	0.648	0.731	0.359
10 - 20u	0.870	0.875	0.875	0.637
20 - 40u	1.634	1.713	1.468	1.337
40 - 74u	3.148	2.917	2.250	2.078
(0 - 74u, Total)	6.625	6.477	5.780	4.636
74 - 105u	4.240	3.245	3.592	3.215
105 - 150u	5.800	5.092	6.875	5.120
150 - 250u	23.190	24.074	23.125	24.572
Over 250u	60.145	61.112	60.625	62.457

PARTICLE SIZE DISTRIBUTION OF QUARTZ SOIL (SL-4A)

1125-Pound Wheel Load

Particle Size Distribution - Percent by Weight of Dust Fraction, 0 to 74u approx.

	NUMBER OF VEHICLE PASSES						
	0	5	25	75	150	1"Below Surface	1" Above Floor*
0 - 5u	7.5	10.0	10.0	9.7	10.5	10.0	9.5
5 - 10u	14.5	19.0	18.0	18.6	18.0	16.0	15.0
10 - 20u	18.0	22.0	18.0	20.7	20.0	18.0	16.5
20 - 40u	21.5	23.5	24.0	24.5	24.5	27.5	24.0
40 - 74u	36.5	24.5	29.0	26.0	27.0	28.5	33.0
Over 74u	2.0	1.0	1.0	0.5	0	0	2.0
Median Size	28.2	19.5	23.0	20.5	21.0	23.5	26.8
Particle Size Distribution - Percent by Weight of Total Sample							
0 - 5u	.60	.67	.79	.88	.79	.64	.63
5 - 10u	1.15	1.28	1.43	1.67	1.35	1.03	1.00
10 - 20u	1.44	1.47	1.43	1.87	1.50	1.15	1.11
20 - 40u	1.67	1.58	1.91	2.20	1.84	1.76	1.61
40 - 74u	2.91	1.64	2.30	2.34	2.02	1.83	2.21
(0 - 74u, Total)	7.77	6.64	7.86	8.96	7.50	6.41	6.56
74 - 105u	3.92	3.42	2.41	2.04	3.33	2.56	2.81
105 - 150u	5.16	4.47	5.14	5.00	6.25	6.41	5.35
150 - 250u	17.85	17.32	16.82	17.00	17.08	17.95	16.08
Over 250u	65.30	68.15	67.77	67.00	65.84	66.67	69.20

***Sample 1" Below surface came to surface after 75 passes.**
Sample pan 1" above floor came to surface after 125 passes.

PARTICLE SIZE DISTRIBUTION
OF
LIMESTONE SOIL
(SL-5)
750-Pound Wheel Load

Particle Size Distribution - Percent by Weight of Dust Fraction, 0 to 74u approx.							
	NUMBER OF VEHICLE PASSES						
	0	1	5	10	25	50	100
0 - 5u	13.7	18.5	17.5	19.0	16.0	17.0	15.5
5 - 10u	32.3	30.0	31.0	30.5	28.0	30.0	26.5
10 - 20u	24.3	23.5	24.5	22.5	24.0	25.5	25.0
20 - 40u	16.2	18.0	16.5	17.0	19.0	17.5	20.5
40 - 74u	13.0	10.0	10.5	11.0	13.0	10.0	12.5
Over 74u	0.5	0	0	0	0	0	0
Median Size	10.8	10.3	10.2	10.1	11.5	14.8	12.2
Particle Size Distribution - Percent by Weight of Total Sample							
0 - 5u	1.94	2.51	2.89	2.73	2.57	3.54	2.63
5 - 10u	4.52	4.08	5.13	4.38	4.50	6.25	4.48
10 - 20u	3.40	3.20	4.05	3.23	3.86	5.32	4.24
20 - 40u	2.28	2.45	2.73	2.45	3.05	3.64	3.47
40 - 74u	1.82	1.36	1.73	1.58	2.09	2.08	2.12
(0 - 74u, Total)	13.96	13.60	16.53	14.37	16.07	20.83	16.94
74 - 105u	4.85	3.70	3.05	4.79	8.93	8.33	6.76
105 - 150u	4.65	3.70	3.74	5.37	3.57	6.95	9.40
150 - 250u	6.54	7.40	7.52	10.77	10.72	8.33	9.40
Over 250u	70.00	71.60	69.16	64.70	60.71	55.56	57.50

(Cont'd.)

PARTICLE SIZE DISTRIBUTION OF LIMESTONE SOIL (SL-5)

750-Pound Wheel Load

Particle Size Distribution - Percent by Weight of Dust Fraction, 0 to 74u approx.							
	NUMBER OF VEHICLE PASSES						
	150	200	250	2" Below Surface	3" Below Surface	1" Above Floor	On Floor
0 - 5u	14.0	13 5	16 0	17.5	18.2	17.0	17.5
5 - 10u	27 0	25 5	30.0	31.0	30.3	31.0	31.0
10 - 20u	24 5	25 0	26.5	26.5	25.3	24.0	24.0
20 - 40u	21 0	21.5	18.0	17.0	16.2	18.0	16.0
40 - 74u	13 5	14 5	9.5	8.0	10.0	10.0	11.5
Over 74u	0	0	0	0	0	0	0
Median Size	12.3	12 6	11.0	10.3	10.3	10.5	10.4
Particle Size Distribution - Percent by Weight of Total Sample							
0 - 5u	2 38	1.91	2.85	3.65	3.25	2.56	3.88
5 - 10u	4.59	2.64	5 35	6 45	5.42	4.68	6.90
10 - 20u	4.17	2.59	4.72	5.53	4.52	3.61	5.34
20 - 40u	3 58	2.25	3.20	3.52	2.90	2.72	3.55
40 - 74u	2.28	1.50	1.69	1.67	1.79	1.51	2.56
(0 - 74u, Total)	17 00	10.89	17.81	20.82	17.88	15.08	22.23
74 - 105u	5.45	9 20	8.53	8.33	5.30	3.78	5.56
105 - 150u	7 55	8.05	5.43	4.17	5.30	5.66	6.66
150 - 250u	12 30	13.80	6.98	4.17	7.30	9.45	10.00
Over 250u	57.70	58.06	61.25	62.51	64.22	66.03	55.55

PARTICLE SIZE DISTRIBUTION OF LIMESTONE SOIL (SL-5A)

1125-Pound Wheel Load

Particle Size Distribution - Percent by Weight of Dust Fraction, 0 to 74u approx.							
	NUMBER OF VEHICLE PASSES						
	0	5	25	75	150	1"Below Surface	1" Above Floor
0 - 5u	17.5	16.8	14.0	14.5	13.0	14.0	15.5
5 - 10u	27.5	24.5	21.5	22.0	21.0	21.0	23.0
10 - 20u	26.0	22.7	21.5	18.0	21.5	23.5	20.0
20 - 40u	19.0	22.0	24.5	23.0	26.0	25.0	22.5
40 - 74u	10.0	14.0	18.5	22.5	18.5	16.5	19.0
Over 74u	0	0	0	0	0	0	0
Median Size	11.2	12.6	15.2	16.4	16.2	15.0	14.3
Particle Size Distribution - Percent by Weight of Total Sample							
0 - 5u	1.86	1.23	1.05	.80	1.17	1.82	1.17
5 - 10u	2.90	1.80	1.62	1.21	1.88	2.72	1.74
10 - 20u	2.75	1.66	1.62	.99	1.93	3.05	1.52
20 - 40u	2.01	1.61	1.84	1.26	2.33	3.24	1.70
40 - 74u	1.06	1.05	1.39	1.24	1.66	2.14	1.44
(0 - 74u, Total)	10.58	7.35	7.52	5.50	8.97	12.97	7.57
74 - 105u	7.70	3.90	5.75	4.95	7.78	9.25	7.56
105 - 150u	6.72	7.80	7.08	7.15	11.38	11.10	10.27
150 - 250u	10.58	19.50	25.20	25.25	19.15	22.20	29.75
Over 250u	64.42	61.45	54.45	57.15	52.72	44.48	44.85

PARTICLE SIZE DISTRIBUTION OF BLACK GUMBO SOIL (SL-6)

750-Pound Wheel Load

Particle Size Distribution - Percent by Weight of Dust Fraction, 0 to 74u approx.							
	NUMBER OF VEHICLE PASSES						
	0	1	5	10	25	50	100
0 - 5u	3.5	3.0	5.0	3.8	5.0	5.0	5.5
5 - 10u	6.0	6.5	8.7	6.8	10.0	10.5	10.8
10 - 20u	9.0	9.8	12.8	11.4	15.0	15.5	14.7
20 - 40u	28.0	21.2	27.0	27.0	30.5	29.5	28.0
40 - 74u	52.0	54.5	45.0	50.5	38.7	36.5	39.0
Over 74u	1.5	5.0	1.5	0.5	0.8	3.0	2.0
Median Size	42.0	46.0	37.5	40.8	34.0	33.0	34.2
Particle Size Distribution - Percent by Weight of Total Sample							
0 - 5u	0.026	0.034	0.0580	0.044	0.146	0.337	0.456
5 - 10u	0.044	0.075	0.0885	0.080	0.292	0.643	0.900
10 - 20u	0.065	0.113	0.1300	0.134	0.438	0.950	1.235
20 - 40u	0.205	0.248	0.2745	0.316	0.890	1.830	2.325
40 - 74u	0.378	0.630	0.4575	0.594	1.131	2.240	3.234
(0 - 74u, Total)	0.718	1.100	1.0085	1.168	2.897	6.000	8.150
74 - 105u	0.376	0.826	0.6935	0.790	1.850	2.720	4.320
105 - 150u	1.095	1.154	1.0180	1.152	3.285	3.980	5.190
150 - 250u	1.825	1.536	2.0300	1.570	6.202	8.300	9.680
Over 250u	95.986	95.384	95.2500	95.320	85.766	79.000	72.660

(Cont'd)

PARTICLE SIZE DISTRIBUTION
OF
BLACK GUMBO SOIL
(SL-6)
750-Pound Wheel Load

Particle Size Distribution - Percent by Weight of Dust Fraction, 0 to 74u approx.							
	NUMBER OF VEHICLE PASSES						
	150	200	250	1" Below Surface	2" Below Surface	4" Below Surface	On Floor
0 - 5u	5.7	5.0	5.0	5.7	4.5	3.2	3.5
5 - 10u	9.6	10.5	10.2	9.8	6.5	6.3	5.5
10 - 20u	12.0	13.5	15.8	13.5	9.0	10.6	10.8
20 - 40u	27.7	26.0	26.0	26.5	24.0	28.9	30.4
40 - 74u	43.0	44.0	40.5	43.5	55.0	49.5	48.6
Over 74u	2.0	1.0	2.5	1.0	1.0	1.5	1.2
Median Size	36.5	36.0	33.5	35.7	44.0	41.0	39.8
Particle Size Distribution - Percent by Weight of Total Sample							
0 - 5u	0.511	0.550	0.618	1.24	0.470	0.193	0.081
5 - 10u	0.858	1.145	1.260	2.12	0.680	0.382	0.127
10 - 20u	1.075	1.470	1.950	2.92	0.940	0.645	0.249
20 - 40u	2.480	2.830	3.210	5.75	2.520	1.760	0.703
40 - 74u	3.850	4.800	5.010	9.40	5.750	3.020	1.125
(0 to 74u, Total)	8.774	10.795	12.048	21.43	10.360	6.000	2.285
74 - 105u	3.906	5.200	5.180	11.04	7.000	4.880	1.765
105 - 150u	5.220	5.805	6.362	12.18	9.300	6.520	2.890
150 - 250u	8.950	10.200	8.610	15.55	13.370	12.600	6.930
Over 250u	73.150	68.000	67.800	39.80	59.970	70.000	86.130

PARTICLE SIZE DISTRIBUTION
OF
BLACK GUMBO SOIL
(SL-6A)
1125-Pound Wheel Load

Particle Size Distribution - Percent by Weight of Dust Fraction, 0 to 74u approx.							
	NUMBER OF VEHICLE PASSES						
	0	5	25	75	150	1" Below Surface	1" Above Floor
0 - 5u	2.0	2.6	5.3	4.5	7.5	5.5	4.0
5 - 10u	4.0	5.8	8.2	8.0	12.5	9.5	8.5
10 - 20u	5.0	9.6	13.3	9.5	12.0	15.0	12.5
20 - 40u	12.5	26.0	29.0	19.0	19.5	29.0	28.5
40 - 74u	75.0	55.0	43.7	56.0	47.0	40.5	45.5
Over 74u	1.5	1.0	.5	3.0	1.5	.5	1.0
Median Size	52.0	44.0	35.8	46.0	38.0	33.5	37.5
Particle Size Distribution - Percent by Weight of Total Sample							
0 - 5u	.02	.04	.21	.54	1.01	.68	.09
5 - 10u	.04	.10	.33	.97	1.68	1.17	.19
10 - 20u	.05	.17	.53	1.13	1.61	1.85	.28
20 - 40u	.36	.45	1.15	2.26	2.62	3.57	.63
40 - 74u	.82	.95	1.74	6.67	6.30	4.98	1.01
(0 - 74u, Total)	1.29	1.71	3.96	11.57	13.22	12.25	2.20
74 - 105u	1.10	1.75	2.50	5.70	5.67	4.85	1.52
105 - 150u	1.61	2.31	3.48	7.73	6.96	7.53	3.70
150 - 250u	4.80	6.36	7.46	11.90	11.95	11.65	9.62
Over 250u	91.20	87.87	82.60	63.09	62.20	63.72	82.96

PARTICLE SIZE DISTRIBUTION
OF
DECOMPOSED GRANITE
(SL-7)
750-Pound Wheel Load

Particle Size Distribution - Percent by Weight of Dust Fraction, 0 to 74u approx.							
	NUMBER OF VEHICLE PASSES						
	0	1	5	10	25	50	100
0 - 5u	10.5	10.0	12.8	14.0	10.5	13.0	14.0
5 - 10u	25.5	24.2	26.7	29.5	25.5	26.5	28.0
10 - 20u	28.0	26.3	22.7	21.0	26.8	21.5	21.2
20 - 40u	19.5	23.5	19.5	13.7	17.7	15.0	16.3
40 - 74u	16.5	16.0	18.3	21.8	19.5	23.0	20.0
Over 74u	0	0	0	0	0	0	0
Median Size	13.3	14.6	13.2	11.9	13.5	13.2	12.2
Particle Size Distribution - Percent by Weight of Total Sample							
0 - 5u	0.273	0.354	0.610	0.725	0.740	1.155	1.322
5 - 10u	0.664	0.854	1.270	1.530	1.795	2.355	2.641
10 - 20u	0.730	0.930	1.080	1.090	1.885	1.910	2.000
20 - 40u	0.507	0.832	0.928	0.710	1.245	1.335	1.530
40 - 74u	0.430	0.565	0.872	1.130	1.370	2.045	1.890
(0 - 74u, Total)	2.604	3.535	4.760	5.185	7.035	8.800	9.383
74 - 105u	1.041	1.515	1.905	2.075	2.110	2.860	3.380
105 - 150u	1.561	2.020	2.875	2.590	3.520	3.890	3.882
150 - 250u	2.604	4.030	7.140	6.220	6.335	6.660	6.665
Over 250u	92.190	88.900	83.320	93.930	81.000	77.790	76.690

(Cont'd.)

PARTICLE SIZE DISTRIBUTION OF DECOMPOSED GRANITE (SL-7)

750-Pound Wheel Load

Particle Size Distribution - Percent by Weight of Dust Fraction, 0 to 74u approx.							
	NUMBER OF VEHICLE PASSES						
	150	200	250	1" Below Surface	2" Below Surface	4" Below Surface	On Floor
0 - 5u	13.0	13.5	13.5	12.0	12.5	11.0	10.0
5 - 10u	26.0	27.5	25.5	25.0	24.3	27.5	20.0
10 - 20u	26.0	23.0	23.0	26.0	21.2	23.5	20.5
20 - 40u	15.0	16.0	16.0	19.0	19.5	16.0	17.5
40 - 74u	19.2	21.5	21.5	17.5	22.0	21.0	31.5
Over 74u	0.8	0.5	0.5	0.5	0.5	1.0	0.5
Median Size	12.8	13.2	13.2	13.4	13.8	13.7	19.6
Particle Size Distribution - Percent by Weight of Total Sample							
0 - 5u	1.25	1.300	1.40	1.20	1.24	1.17	1.15
5 - 10u	2.51	2.690	2.65	2.50	2.40	2.84	2.30
10 - 20u	2.51	2.610	2.38	2.60	2.10	2.48	2.36
20 - 40u	1.45	1.200	1.67	1.90	1.93	1.65	2.01
40 - 74u	1.86	2.200	2.23	1.75	2.17	2.16	3.62
(0 - 74u, Total)	9.58	10.00	10.33	9.95	9.84	10.30	11.44
74 - 105u	1.46	3.500	2.65	1.97	2.71	3.12	4.48
105 - 150u	3.22	4.000	3.88	4.62	3.80	5.14	6.20
150 - 250u	6.94	7.500	8.44	9.61	9.12	9.44	10.52
Over 250u	78.80	75.000	74.70	73.85	74.53	72.00	67.36

PARTICLE SIZE DISTRIBUTION OF DECOMPOSED GRANITE (SL-7A)

1125-Pound Wheel Load

Particle Size Distribution - Percent by Weight of Dust Fraction, 0 to 74u approx.							
	NUMBER OF VEHICLE PASSES						
	0	5	25	75	150	1" Below Surface	1" Above Surface
0 - 5u	10.0	12.0	13.0	13.0	14.0	12.5	11.5
5 - 10u	22.0	23.5	23.3	29.0	27.5	26.0	25.0
10 - 20u	23.0	23.0	17.4	21.0	24.0	22.0	25.0
20 - 40u	20.8	16.5	14.5	13.0	14.0	14.0	17.0
40 - 74u	23.4	23.5	28.8	23.0	20.0	24.0	21.0
Over 74u	0.8	1.5	3.0	1.0	0.5	1.5	0.5
Median Size	17.4	15.1	16.5	12.4	11.8	13.3	13.9
Particle Size Distribution - Percent by Weight of Total Sample							
0 - 5u	0.61	0.53	1.30	1.79	2.13	1.42	0.76
5 - 10u	1.33	1.05	2.31	4.00	4.19	2.96	1.64
10 - 20u	1.40	1.02	1.73	2.90	3.66	2.51	1.64
20 - 40u	1.26	0.73	1.48	1.79	2.13	1.60	1.12
40 - 74u	1.42	1.05	2.86	3.17	3.05	2.74	1.38
(0 - 74u, Total)	6.02	4.38	9.68	13.65	15.16	11.23	6.54
74 - 105u	2.32	1.97	3.80	4.27	4.35	4.20	3.32
105 - 150u	3.03	3.18	4.67	5.52	4.26	5.37	4.60
150 - 250u	6.81	7.64	8.77	8.98	7.33	9.40	9.20
Over 250u	81.82	82.83	73.08	67.58	68.90	69.80	76.34

PARTICLE SIZE DISTRIBUTION
OF
LEON CREEK BED SOIL
(SL-8)
750-Pound Wheel Load

Particle Size Distribution - Percent by Weight of Dust Fraction, 0 to 74u approx.							
	NUMBER OF VEHICLE PASSES						
	0	1	5	10	25	50	100
0 - 5u	9.5	9.5	9.5	11.0	13.5	15.0	13.5
5 - 10u	19.5	21.7	21.5	24.0	29..0	31.0	28.5
10 - 20u	18.0	21.3	20.5	24.0	26.2	22.5	26.5
20 - 40u	19.0	24.0	24.0	21.0	17.3	16.5	18.0
40 - 74u	33.5	23.2	24.0	19.0	14.0	15.0	13.5
Over 74u	0.5	0.3	0.5	1.0	0	0	0
Median Size	23.0	18.3	18.9	14.0	11.7	10.9	11.8
Particle Size Distribution - Percent by Weight of Total Sample							
0 - 5u	0.058	0.156	0.181	0.350	0.225	0.785	0.698
5 - 10u	0.120	0.357	0.410	0.762	0.483	1.625	1.477
10 - 20u	0.110	0.350	0.390	0.762	0.437	1.180	1.372
20 - 40u	0.117	0.395	0.457	0.667	0.288	0.865	0.932
40 - 74u	0.206	0.382	0.457	0.603	0.234	0.785	0.690
(0 - 74u, Total)	0.611	1.640	1.895	3.144	1.667	5.240	5.169
74 - 105u	0.616	0.334	0.282	0.350	0.278	1.050	2.300
105 - 150u	0.920	0.986	0.818	0.635	1.112	2.095	2.300
150 - 250u	3.680	3.290	3.815	3.171	3.060	3.925	5.170
Over 250u	94.173	93.750	93.190	92.700	93.883	87.690	85.055

(Cont'd)

PARTICLE SIZE DISTRIBUTION
OF
LEON CREEK BED SOIL
(SL-8)
750-Pound Wheel Load

Particle Size Distribution - Percent by Weight of Dust Fraction, 0 to 74u approx.							
	NUMBER OF VEHICLE PASSES						
	150	200	250	1" Below Surface	2" Below Surface	4" Below Surface	On Floor
0 - 5u	16.5	15.5	16.0	18.0	12.0	11.5	9.0
5 - 10u	31.8	31.0	33.0	34.0	27.5	25.5	21.0
10 - 20u	25.7	24.5	26.0	24.5	24.5	23.5	26.0
20 - 40u	14.0	14.5	12.5	13.7	16.0	19.5	19.0
40 - 74u	12.0	14.5	12.5	9.8	20.0	20.0	25.0
Over 74u	0	0	0	0	0	0	0
Median Size	10.3	10.7	10.2	9.6	13.0	13.7	17.6
Particle Size Distribution - Percent by Weight of Total Sample							
0 - 5u	1.16	1.07	1.14	1.82	0.596	0.112	0.080
5 - 10u	2.24	2.15	2.34	3.43	1.360	0.248	0.187
10 - 20u	1.80	1.70	1.85	2.47	1.210	0.229	0.231
20 - 40u	0.98	1.01	0.89	1.38	0.795	0.190	0.168
40 - 74u	0.84	1.01	0.89	0.99	0.993	0.195	0.222
(0 - 74u, Total)	7.02	6.94	7.11	10.09	4.954	0.974	0.888
74 - 105u	1.90	1.74	2.55	3.61	1.986	0.974	0.592
105 - 150u	2.43	2.02	2.28	3.97	2.640	2.600	1.470
150 - 250u	3.78	3.76	3.99	6.13	5.280	6.170	4.150
Over 250u	84.87	85.54	84.07	76.20	85.140	89.282	92.900

PARTICLE SIZE DISTRIBUTION
OF
LEON CREEK BED SOIL
(SL-8A)
1125-Pound Wheel Load

Particle Size Distribution - Percent by Weight of Dust Fraction, 0 to 74u approx.							
	NUMBER OF VEHICLE PASSES						
	0	5	25	75	150	1" Below Surface	1" Above Surface
0 - 5u	7.0	10.0	11.5	13.5	14.0	12.2	15.5
5 - 10u	16.5	22.0	26.0	27.0	26.5	24.8	27.5
10 - 20u	18.5	23.5	24.5	25.5	24.5	22.8	22.5
20 - 40u	23.2	24.5	21.0	18.0	18.0	18.2	16.5
40 - 74u	32.0	20.0	17.0	16.0	17.0	22.0	18.0
Over 74u	2.8	0	0	0	0	0	0
Median Size	26.0	16.7	13.2	12.3	12.2	13.5	11.7
Particle Size Distribution - Percent by Weight of Total Sample							
0 - 5u	0.075	0.150	0.422	0.74	0.80	0.75	1.39
5 - 10u	0.178	0.330	0.958	1.49	1.51	1.52	2.46
10 - 20u	0.200	0.353	0.905	1.41	1.40	1.40	2.01
20 - 40u	0.248	0.368	0.775	0.99	1.03	1.12	1.48
40 - 74u	0.344	0.300	0.625	0.88	0.97	1.35	1.61
(0 - 74u, Total)	1.045	1.501	3.685	5.51	5.71	6.14	8.95
74 - 105u	0.570	0.376	1.230	1.47	3.04	2.70	3.25
105 - 150u	0.539	0.752	2.460	2.58	2.28	3.46	2.84
150 - 250u	1.613	3.008	5.735	5.51	5.32	9.22	7.31
Over 250u	96.233	94.363	86.890	84.93	83.65	78.48	77.65

PARTICLE SIZE DISTRIBUTION
OF
CLAY-SAND SOIL
(SL-9)
750-Pound Wheel Load

Particle Size Distribution - Percent by Weight of Dust Fraction, 0 to 74u approx.							
	NUMBER OF VEHICLE PASSES						
	0	1	5	10	25	50	100
0 - 5u	10. 2	8. 0	8. 5	10. 0	10. 0	10. 2	11. 5
5 - 10u	17. 6	12. 0	14. 3	16. 5	15. 3	17. 0	20. 5
10 - 20u	14. 9	9. 0	14. 2	9. 5	15. 0	15. 6	23. 0
20 - 40u	11. 8	11. 0	11. 2	13. 0	10. 9	10. 2	14. 0
40 - 74u	44. 5	59. 0	50. 1	50. 5	47. 5	45. 5	30. 5
Over 74u	1. 0	1. 0	1. 7	0. 5	1. 3	1. 5	0. 5
Median Size	33. 5	47. 4	42. 0	41. 0	38. 0	35. 0	16. 8
Particle Size Distribution - Percent by Weight of Total Sample							
0 - 5u	0. 755	0. 580	0. 85	1. 12	1. 26	1. 30	2. 02
5 - 10u	1. 302	0. 870	1. 44	1. 85	1. 94	2. 17	3. 60
10 - 20u	1. 103	0. 652	1. 43	1. 07	1. 90	2. 00	4. 05
20 - 40u	0. 874	0. 798	1. 12	1. 46	1. 38	1. 30	2. 46
40 - 74u	3. 295	4. 280	5. 04	5. 67	6. 00	5. 80	5. 36
(0 - 74u, Total)	7. 329	7. 180	9. 88	11. 17	12. 48	12. 57	17. 49
74 - 105u	2. 295	2. 240	3. 31	3. 42	2. 92	4. 63	5. 04
105 - 150u	2. 221	4. 350	4. 40	3. 93	4. 40	5. 55	6. 05
150 - 250u	2. 960	5. 800	6. 91	6. 74	7. 70	8. 90	10. 42
Over 250u	85. 195	80. 430	75. 50	74. 74	72. 50	68. 35	61. 00

(Cont'd)

PARTICLE SIZE DISTRIBUTION OF CLAY-SAND SOIL (SL-9)

750-Pound Wheel Load

Particle Size Distribution - Percent by Weight of Dust Fraction, 0 to 74u approx.							
	NUMBER OF VEHICLE PASSES						
	150	200	250	1"Below Surface	2"Below Surface	4"Below Surface	On Floor
0 - 5u	11.5	15.0	14.5	11.0	8.7	6.0	7.0
5 - 10u	23.5	25.0	23.0	20.0	13.8	11.0	12.5
10 - 20u	26.5	22.8	21.0	16.0	13.3	15.0	14.5
20 - 40u	12.0	9.0	11.0	10.0	9.7	11.5	14.5
40 - 74u	26.5	28.2	30.5	42.0	52.0	54.5	51.0
Over 74u	0	0	0	1.0	2.5	2.0	0.5
Median Size	13.7	13.2	14.0	25.5	44.5	46.0	42.0
Particle Size Distribution - Percent by Weight of Total Sample							
0 - 5u	2.32	2.86	3.07	1.45	1.07	0.592	0.94
5 - 10u	4.72	4.78	4.87	2.65	1.70	1.085	1.67
10 - 20u	5.32	4.35	4.44	2.12	1.64	1.480	1.93
20 - 40u	2.42	1.74	2.33	1.32	1.19	1.131	1.93
40 - 74u	5.32	5.38	6.45	5.56	6.40	5.370	6.78
(0 - 74u, Total)	20.10	19.11	21.16	13.10	12.00	9.658	13.25
74 - 105u	4.85	5.73	4.81	6.02	5.12	4.150	4.32
105 - 150u	4.85	6.36	5.28	5.88	4.80	5.925	6.92
150 - 250u	9.70	10.20	8.17	9.56	10.18	11.107	11.15
Over 250u	60.50	58.60	60.58	65.44	67.90	69.160	64.36

PARTICLE SIZE DISTRIBUTION OF CLAY-SAND SOIL (SL-9A)

1125-Pound Wheel Load

Particle Size Distribution - Percent by Weight of Dust Fraction, 0 to 74u approx.							
	NUMBER OF VEHICLE PASSES						
	0	5	25	75	150	1" Below Surface	1" Above Surface
0 - 5u	6.5	8.0	9.5	13.8	11.0	6.7	5.0
5 - 10u	10.0	16.0	17.7	23.7	22.0	12.3	10.5
10 - 20u	8.3	15.0	16.8	22.5	21.5	12.3	12.0
20 - 40u	15.2	12.0	12.0	13.0	17.5	12.2	13.0
40 - 74u	57.3	48.0	42.7	27.0	27.5	54.5	57.5
Over 74u	2.7	1.0	1.3	0	0.5	2.0	2.0
Median Size	49.2	39.0	30.0	13.7	17.2	46.0	47.5
Particle Size Distribution - Percent by Weight of Total Sample							
0 - 5u	0.32	0.55	1.32	2.41	2.14	0.87	0.49
5 - 10u	0.49	1.11	2.45	4.14	4.30	1.64	1.02
10 - 20u	0.41	1.04	2.33	3.93	4.20	1.64	1.17
20 - 40u	0.75	0.83	1.66	2.26	3.42	1.61	1.27
40 - 74u	2.83	3.34	5.90	4.70	5.37	7.18	5.60
(0 - 74u, Total)	4.80	6.87	13.66	17.44	19.43	12.94	9.55
74 - 105u	1.98	2.96	3.80	4.65	5.58	5.52	4.46
105 - 150u	3.72	2.89	4.22	5.82	7.60	5.79	5.48
150 - 250u	5.55	6.36	7.82	9.30	8.70	12.10	10.36
Over 250u	83.95	80.92	70.50	62.79	58.69	63.65	70.15

APPENDIX C

Appendix C contains a graphic presentation of data found in Appendix B.

The specific percentage of "below 74 micron particles" of the total soil sample versus the number of vehicle passes is shown. Due to the variation and minimum plot points, straight semilog curves are fashioned. The straight line curves assume the mathematical relation:

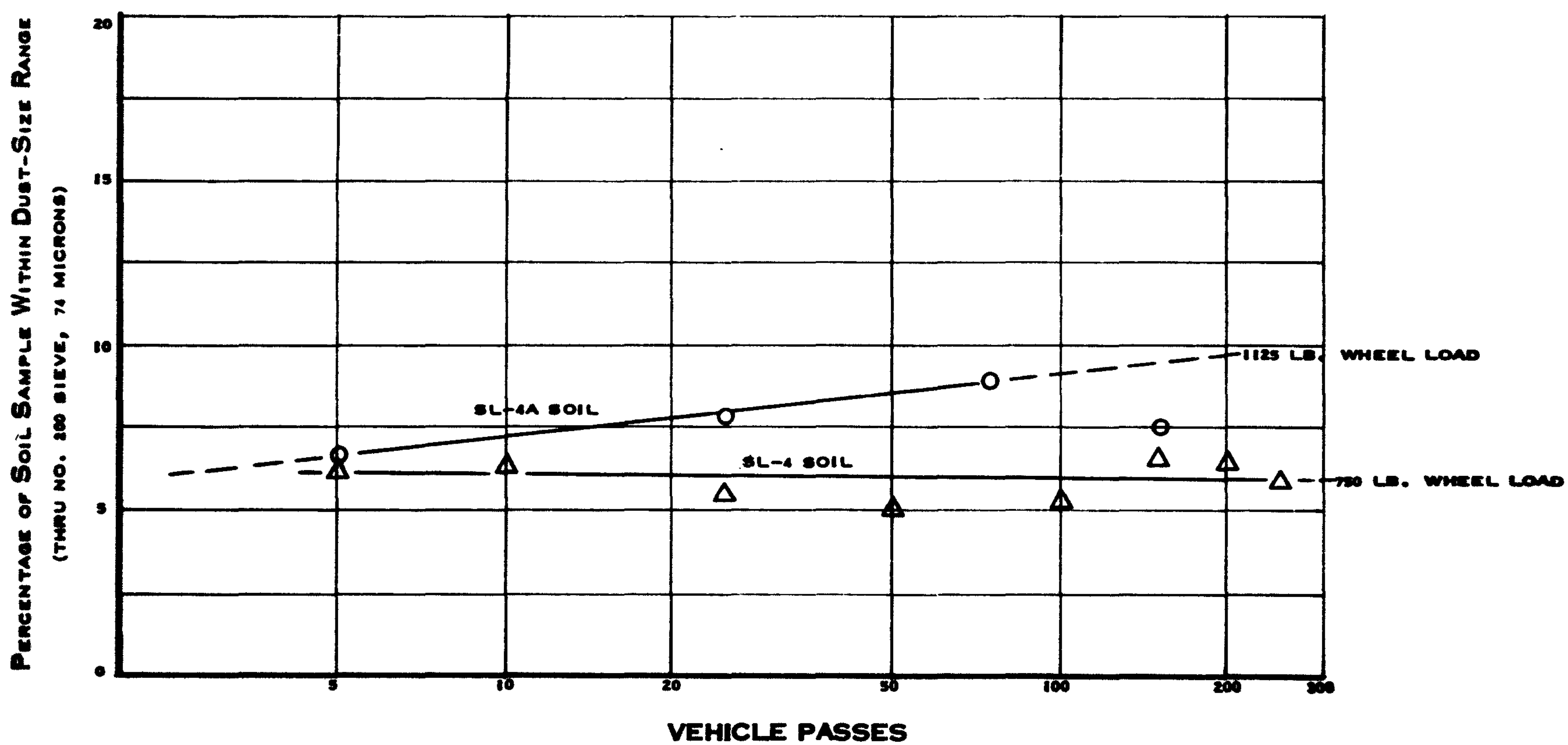
$$p = \frac{\log R - \log C}{m \log 10}$$

where C and m are constants

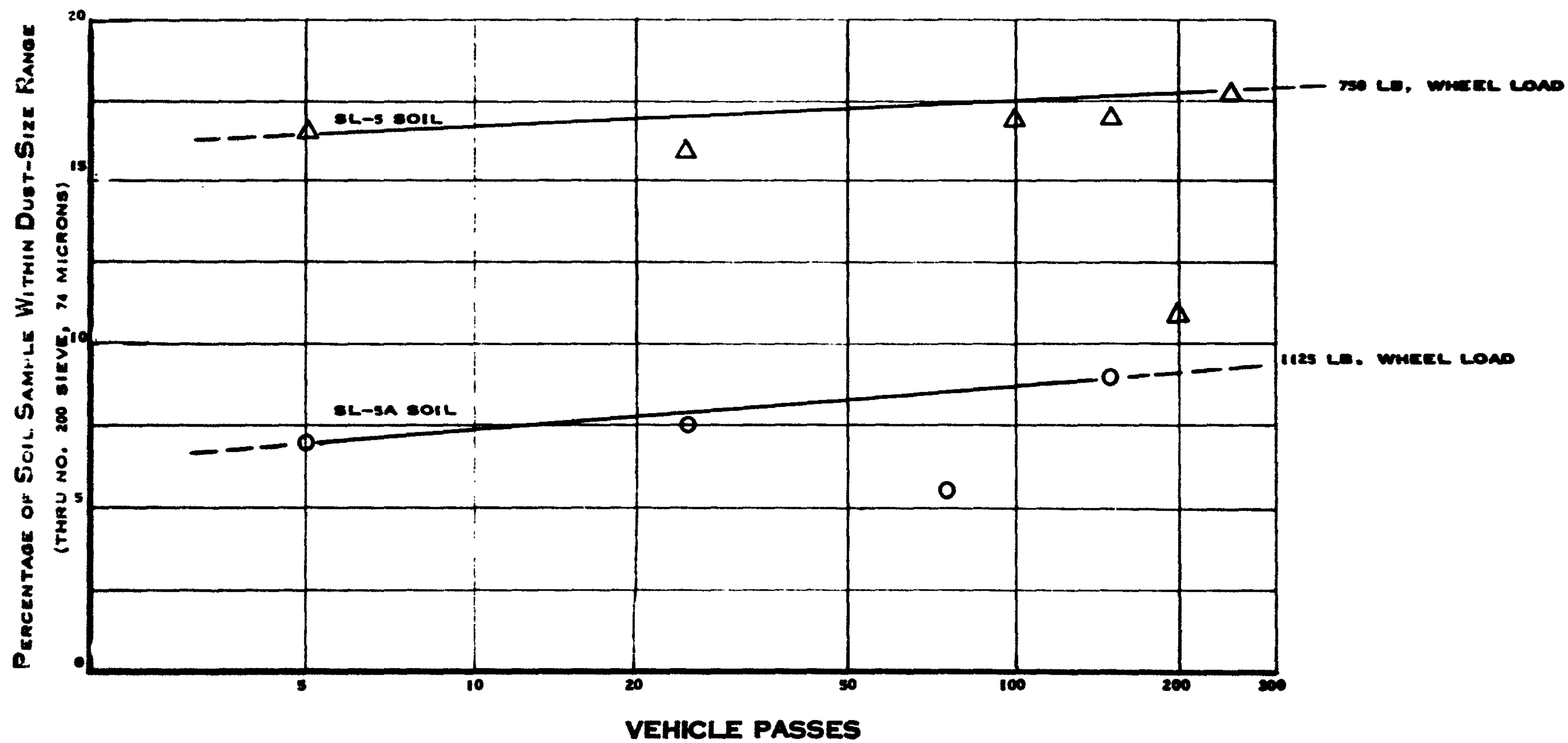
and p = percent of total sample within the dust size (0-74 micron) fraction

and R = number of vehicle passes over the soil prior to collection of sample

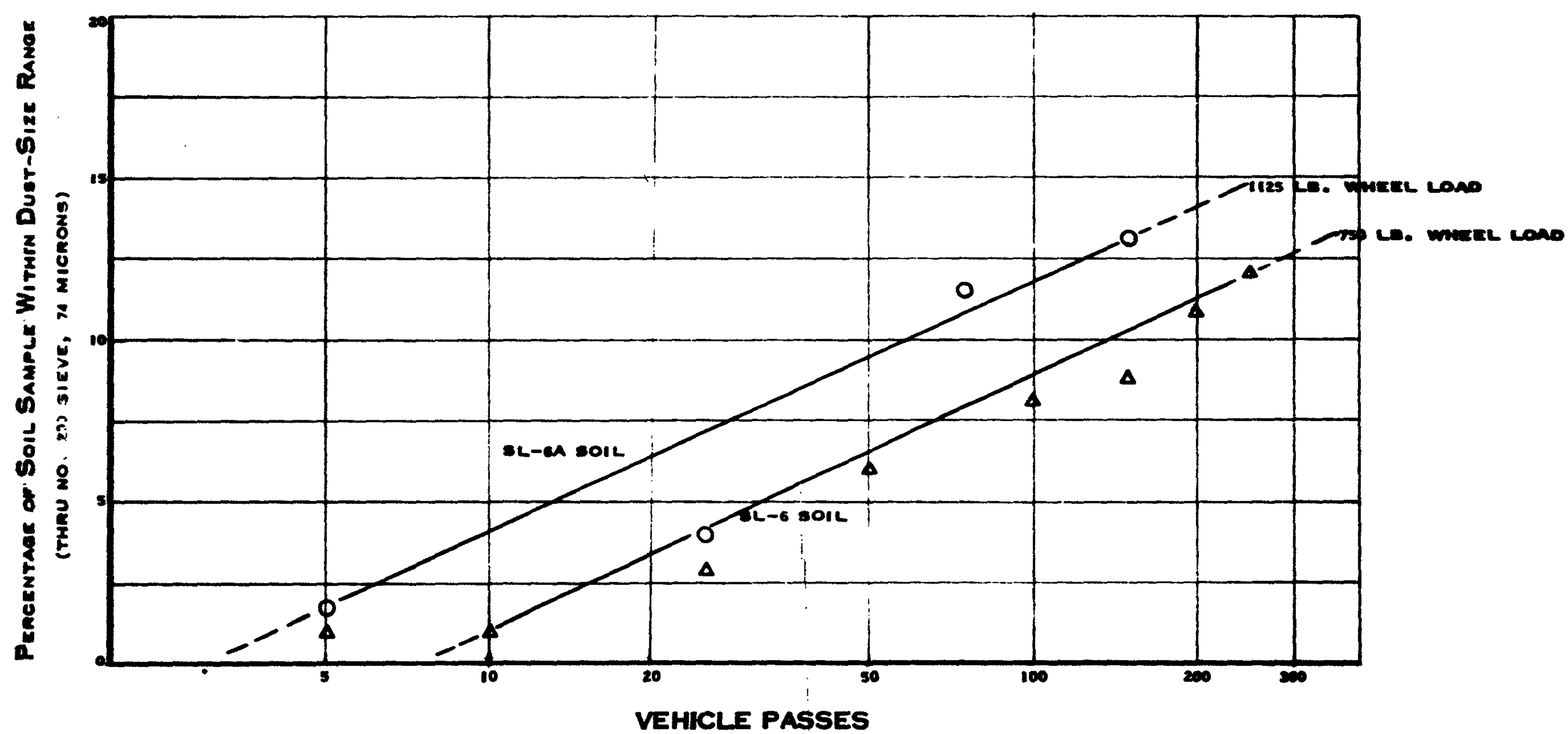
The two curves for each soil type are for two different wheel loads. The plot points extend through the 150th run for the 1125-pound per wheel load, and through the 250th run for the 750-pound per wheel load. Dashed lines are merely extrapolations of experimental data.



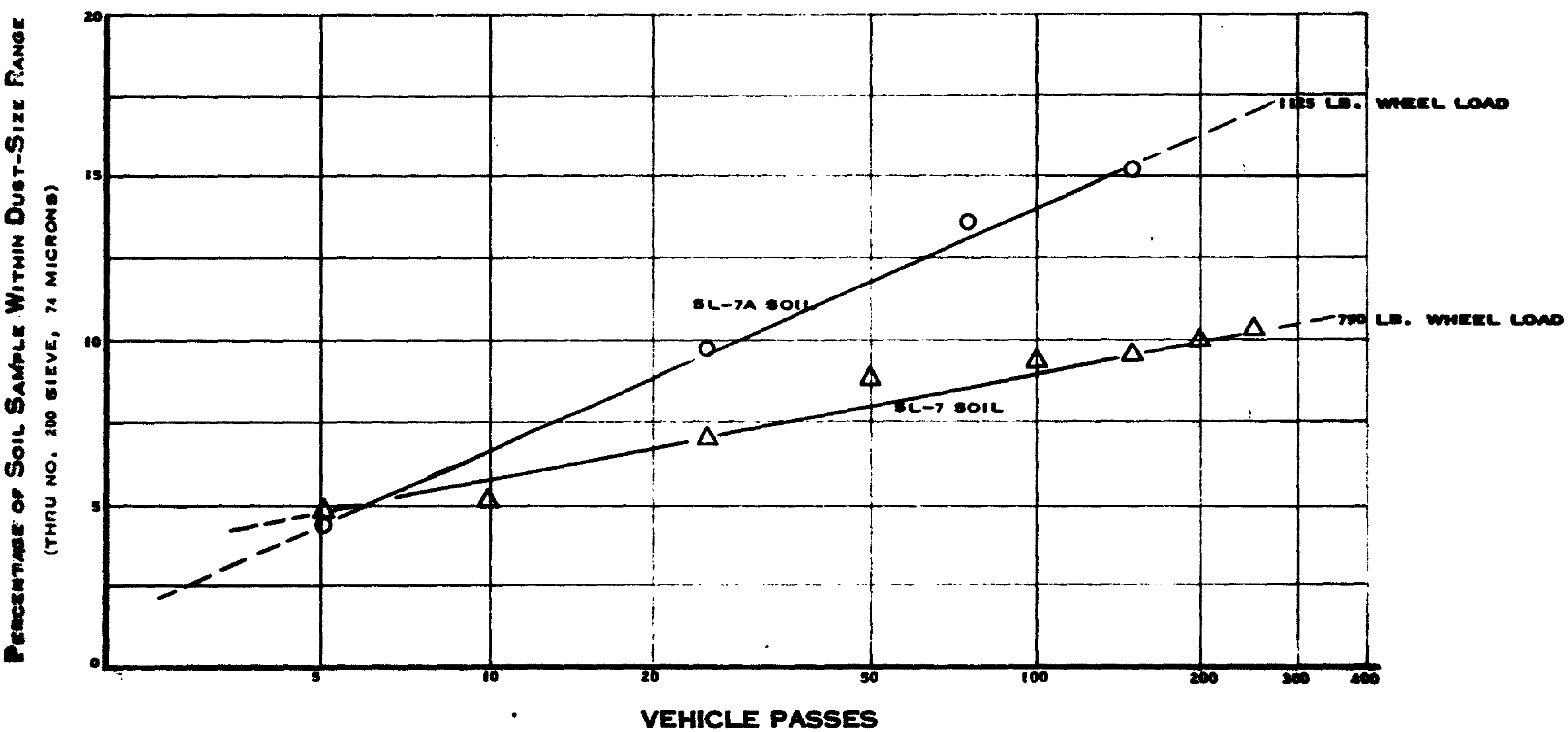
Deagglomeration of Quartz Soil by Vehicle Traffic With Different Wheel Loads



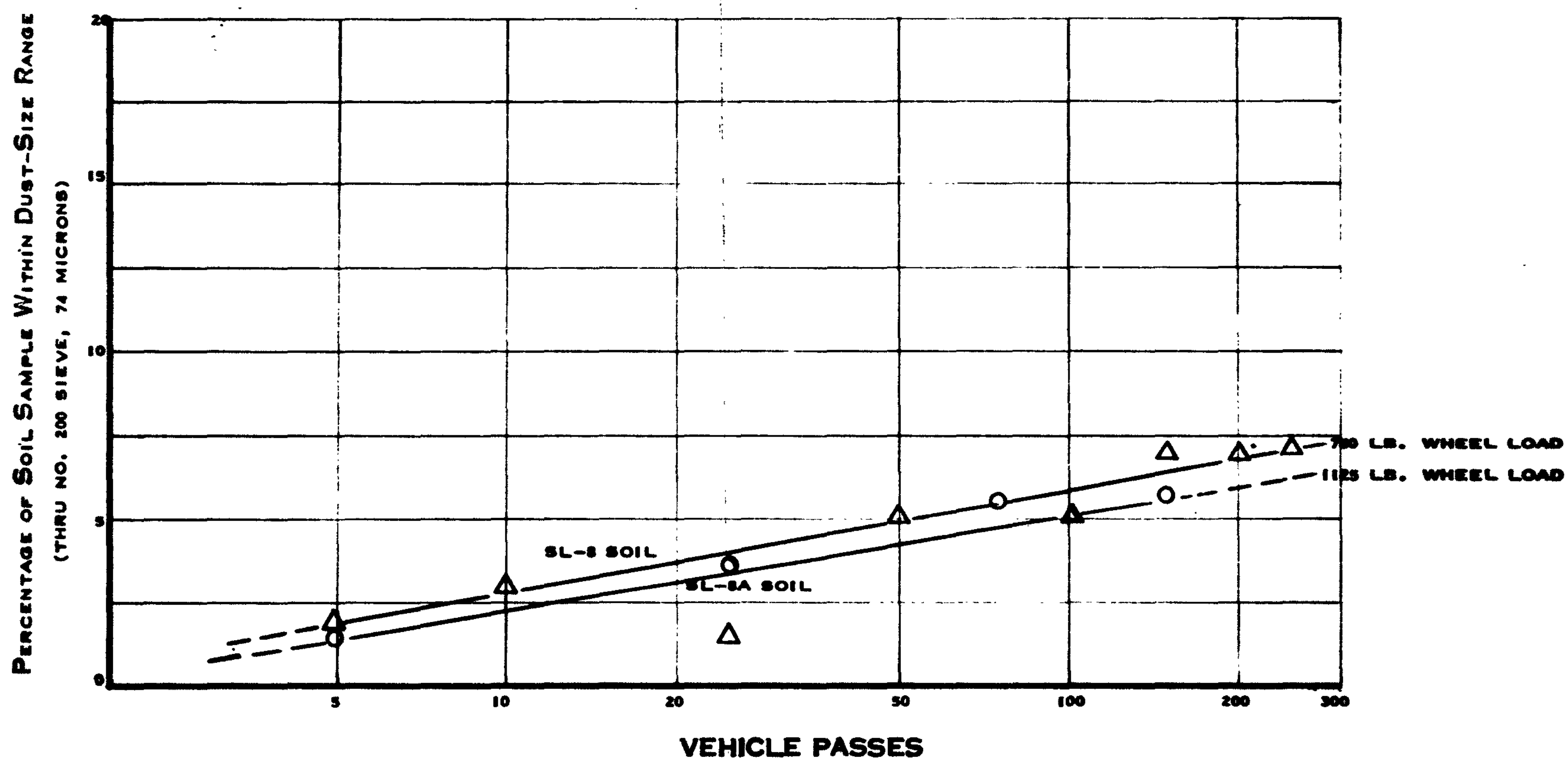
Deagglomeration of Soft Limestone Soil by Vehicle Traffic
With Different Wheel Loads



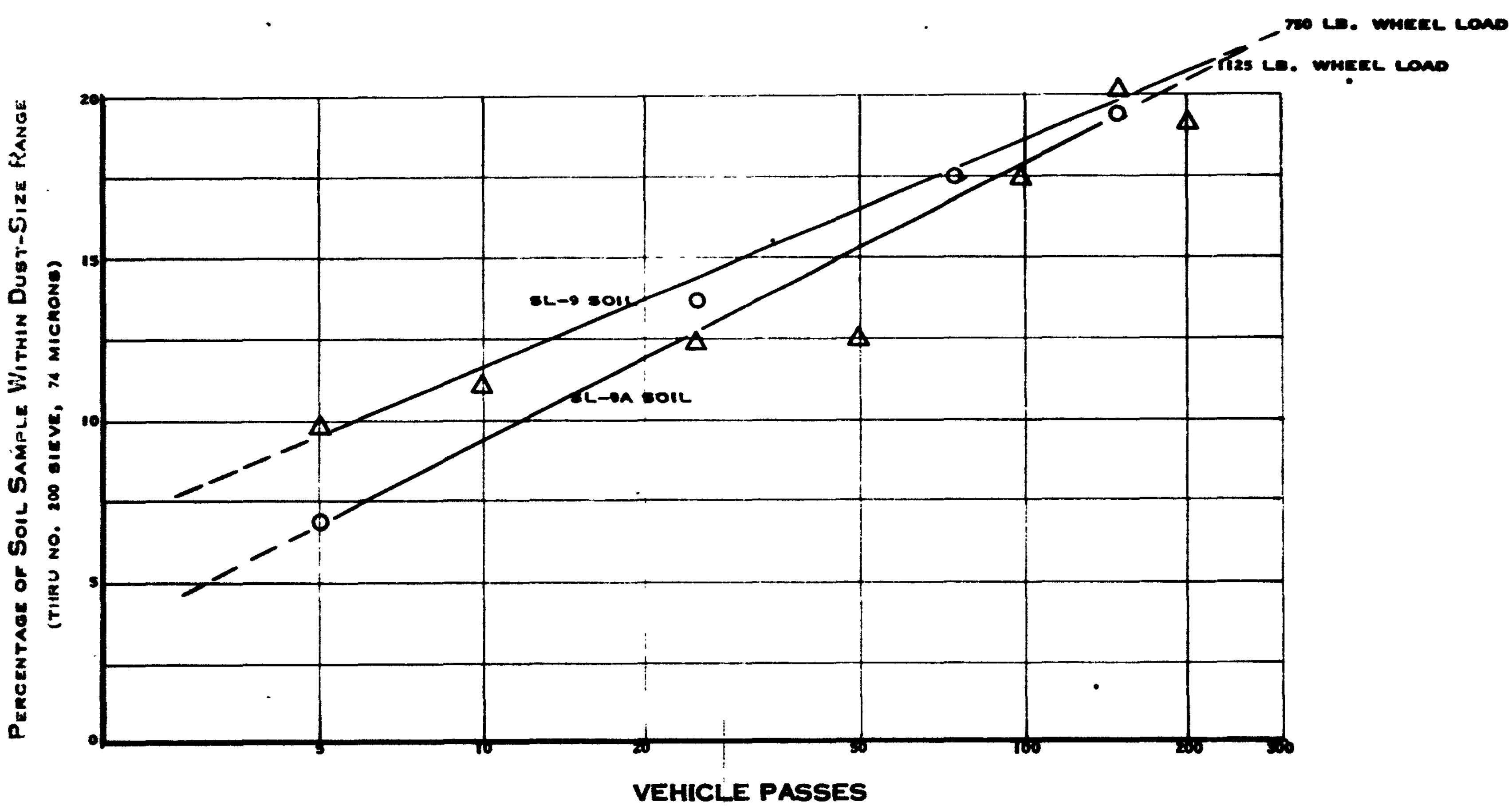
Deagglomeration of Black Clay Gumbo Soil by Vehicle Passes
With Different Wheel Loads



DEAGGLOMERATION OF DECOMPOSED GRANITE SOIL BY VEHICLE TRAFFIC WITH DIFFERENT WHEEL LOADS



Deagglomeration of Leon Creek Sand-Gravel-Clay Soil by Vehicle Traffic With Different Wheel Loads



DEAGGLOMERATION OF CLAY SOIL BY VEHICLE TRAFFIC
WITH DIFFERENT WHEEL LOADS

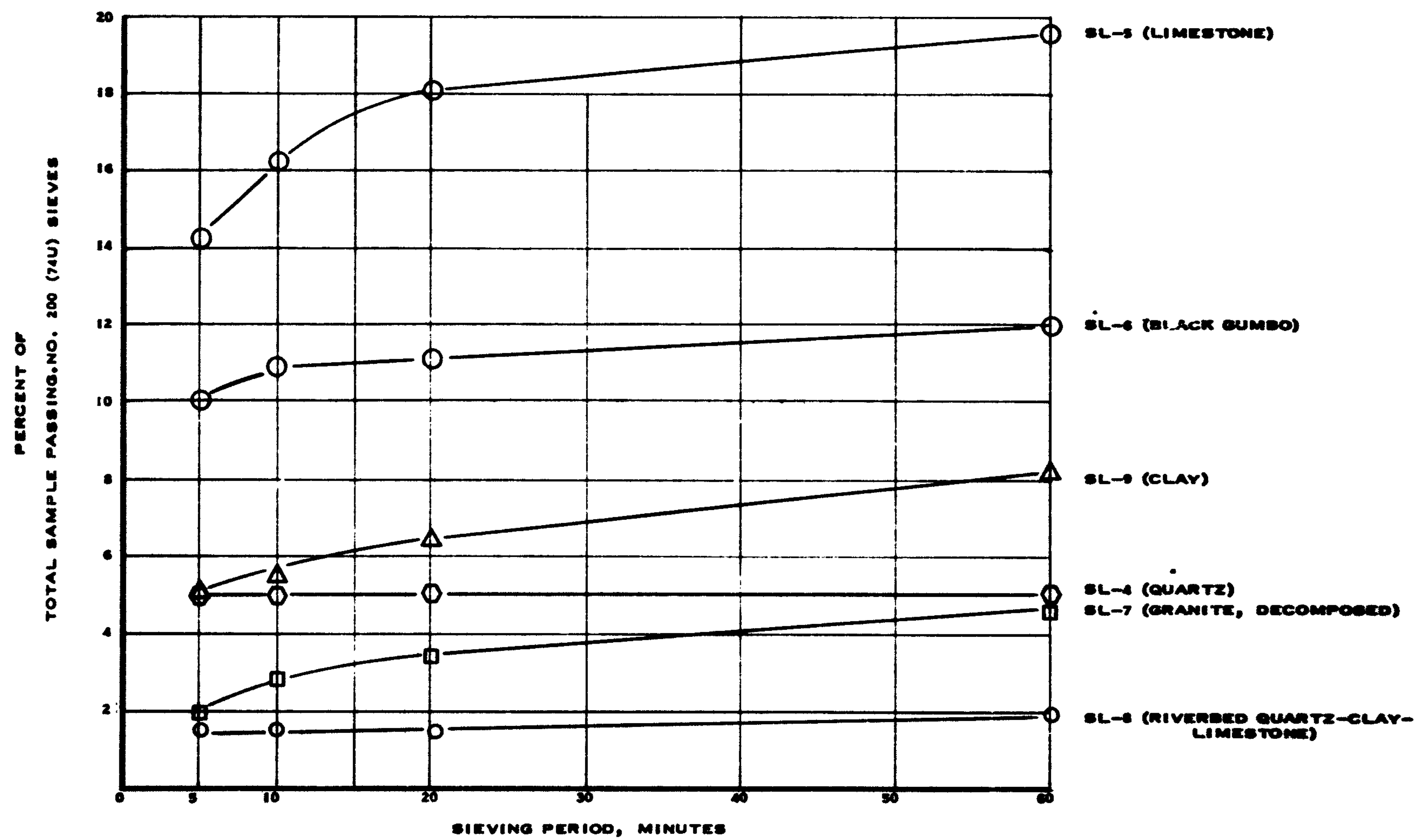
APPENDIX D

Appendix D contains two important graphical illustrations to signify:

(1) The sieving rate for each of the six soils used in this program. [The sieving rate is the percentage of a soil sample passing the No. 200 (74 micron) sieve with continued shaking.]

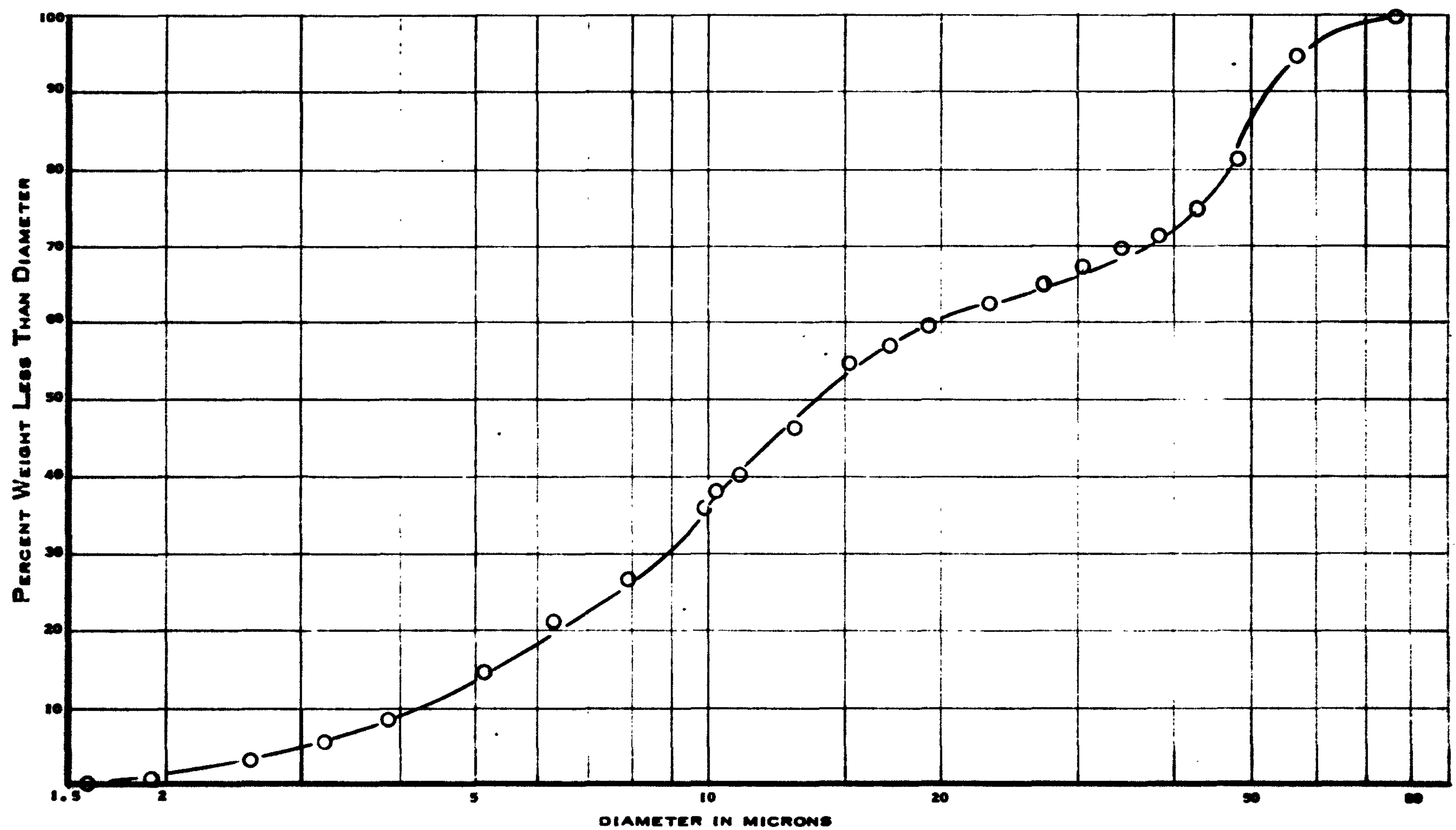
(2) The particle size distribution (0 to 74 microns) of the same soil (SL-9, after 150 runs) exhibiting two materials, resulting in a "double-S" distribution curve.

VARIATION IN SIEVING RATE FOR DIFFERENT SOILS



PARTICLE SIZE DISTRIBUTION ANALYSIS

SAMPLE CURVE, SL-9 (CLAY) SOIL



750—LB. LOAD PER WHEEL, AFTER 250 VEHICLE PASSES

NOTE: THE CURVE DOES NOT AGREE PRECISELY WITH NUMERICAL DATA IN APPENDIX B, SINCE THE TABULATED DATA ARE AVERAGE OF TWO ANALYSES (CURVES) OF EACH SAMPLE.

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DEVELOPMENT OF A SOIL SAMPLING TECHNIQUE AND MEASUREMENT OF DEAGGLOMERATION OF SIX SOILS TO DETERMINE DUST PRODUCING CAPABILITY
Carl A. Hafer

October 1960, 72 pp incl appendixes. Final report on Task Order No. 1 (Contract No. DA-23-072-ORD-1375). Unclassified Report

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2. Soils -- Mechanical properties
3. Soils -- Test Methods

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